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Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/16 in., FLC, H.R. (our rope #5)

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CANADA/NB MDA PROJECT ON MINE-SHAFT ROPE TESTING; TESTING OF $1\frac{7}{16}$ IN., FLC, H.R. (OUR ROPE #5)

by

L.B. Geller*, D. Poffenroth†, J.E. Udd**, and D. Hutchinson††

ABSTRACT

In this report the authors analyse the test-results that were obtained both non-destructively, and destructively, on a $1\frac{7}{16}$ in., 1×176, full-locked-coil (FLC) hoist rope. The rope was examined both in situ and on the shop-floor as part of CANMET's project to comparatively evaluate the performance of a range of EM wire-rope testers. This is the first time a project of this magnitude and diversity has been undertaken.

The rope in question had two short, relatively sound, sections at both ends, followed by rapid deterioration. There is a long stretch of uniformly corroded central rope section. Conditions along the rope were, more or less, symmetrical.

In the field EM testing was performed with a Rotesco AC, Magnograph, and LMA-250 instrument. Six months later the rope was also tested reel-to-reel on the shop-floor, with a range of five instruments.

The reported loss-of-metallic-area (LMA) values differed widely.

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Keywords: New Brunswick; Mineral Development Agreement; Wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Locked-coil ropes

PROJET DE L'EEM CANADA-N.-B. SUR DES ESSAIS DE CÂBLES POUR PUITS DE MINE; ESSAIS DU CÂBLE DE LEVAGE À VERROUILLAGE COMPLET DE 1 7/16 PO (NOTRE CÂBLE N°5)

par

L.B. Geller*, D. Poffenroth+, J.E. Udd** et D. Hutchinson++

RÉSUMÉ

Dans le présent rapport, les auteurs analysent les résultats d'essais non destructifs et destructifs sur un câble de levage à verrouillage complet de 1 7/16 po, 1 x 176. L'analyse du câble a eu lieu in situ et sur le plancher de l'atelier dans le cadre du projet de CANMET visant à effectuer une évaluation comparative du rendement d'une gamme d'appareils d'essai EM. C'est la première fois que l'on entreprend un projet d'une telle envergure et aussi diversifiée.

Le câble en question comportait deux courtes parties en relativement bon état aux deux extrémités, suivies d'une partie à détérioration rapide. Au centre du câble, on observe une longue corrosion uniforme. Les conditions le long du câble étaient plus ou moins symétriques.

Sur le terrain, les essais EM ont été réalisés en utilisant un Rotesco AC, un Manograph et un LMA-250. Six mois plus tard, on a effectué des essais de dévidoir à dévidoir sur le plancher de l'atelier avec une gamme de cinq instruments.

Les valeurs de la perte de zone métallique indiquées ont grandement différé.

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Mots clés : Nouveau-Brunswick; Entente sur l'exploitation minérale; câbles; essai non destructif; instruments électromagnétiques; câbles à verrouillage

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BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in 1986 in response to requests by both the mining industry and its regulators. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be examined, analysed, and clarified. This is the first time a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (1, 2, 3, 4). We are now in the process of reporting the results obtained during the contracted project-phase, which included an extensive series of in situ and shop-floor tests. The first three reports of this series were published in February, May, and June, 1990 (5, 6, 7). This is the fourth such report. More are to follow.

ROPE DETAILS

The rope of current interest (referred to as "our rope #5") was designated #2 Head Rope in Potash Company of America's mine at Sussex, New Brunswick. It was manufactured by Wire Rope Industries Ltd. at Pointe Claire, Quebec. Its reel number was 546760-1, and rope number 909837-01-1. It measured $1\frac{7}{16}$ in. diam × 2,313 ft. It was of a 1 × 176 FLC construction (44 × .125; 18 × .100 × .056; 18 × .108; *outer gallery* : 26 × .095; 21 × .095; 16 × .092; 8 × .080; *inner gallery* : 8 × .060; 8 × .090; 8 × .047; 1 × .080 *in.*), with a mass of 4.85 lb/ft; right-lay; bright steel. Its breaking strength was 274,800 lb (Ont. MOL test certificate #65926). It was purchased on 23.1.86; installed on 4.8.87 and removed on 24.11.88 (i.e., it was in use for $15\frac{1}{2}$ months).

Its predecessor had the reel number R2-P8737-FH234, and rope number PH2. It was manufactured by TECNOR in France, and was purchased on 16.9.85 (shipped on 7.1.86). It measured $1\frac{7}{16}$ in. diameter × 2,313 ft. It was of a 1 × 148 FLC construction (41 × .118 *outer full − lock*; 18 × .108, 18 × .108, 22 × .110, *first inner gallery*; 12 × .098, 12 × .098, *second inner gallery*; 12 × .111, 6 × .051, 6 × .124, 1 × .139 *in., centre*), with a mass of 4.85 lb/ft; right lay outer gallery; bright steel. Its breaking strength was 279,022 lb (tested by TECNOR on 3.1.86). It was installed on 29.7.86 and removed on 4.8.87 (12 months in use).

IN SITU TEST RESULTS — AS REPORTED AND REVIEWED

In situ test results were obtained with the Rotesco AC, the Magnograph, and the LMA-250 instruments.

The 1986-1987 rope was EM tested with a Rotesco AC instrument on 10.9.86 (test #DI-MP-36) and on 9.3.87 (test #DMP-34). The maximum reported loss-of-breaking strength (LBS) values were 1.5% and 2.0%, respectively. Losses were, more or less, uniformly distributed along the rope, except for the two rope ends, which were in good shape.

The 1987-1988 rope, of current interest, was also tested with a Rotesco AC instrument at regular intervals, along some 2,100 ft. These tests were undertaken on 1.10.87 (test #DMP-89); on 1.3.88 (test #WMP-27); and on 29.9.88 (test #CBMP-13). The maximum reported LBS values were 1.0% (Fig. 1a); 2.0% (Fig. 1b); and 6.0% (Fig. 2a), respectively. Losses were, more or less, uniformly distributed along the rope, except for the two ends at the skips, which were in much better condition. To better illustrate conditions, we marked up and respliced (Fig. 2b) the original test diagram of 29.9.88. As can be seen, the 0%LMA reference level is at the #1 skip rope end, and the LMA losses are as reported. As usual Rotesco only reported LBS values. We ourselves converted these into the corresponding LMA chart data by dividing the reported LBS values with the appropriate "factor", obtained from the Rotesco AC's operating manual. It lists a factor of 1.53 for a $1\frac{1}{2}$ in. rope. A major Canadian mining company uses a factor of 1.5 for a $1\frac{7}{16}$ in. rope.

After reviewing the reported results, we accepted them.

Subsequently, we too had this rope EM tested in situ, on 19.10.88 with the Magnograph, and on 21.10.88 with the LMA-250 instrument. On both occasions service companies, who owned their instruments, undertook the tests for us. The instrument operators were known to, and approved by, the instrument designers/makers. According to the Magnograph operator's report (report #88-525B), a maximum LMA of 9.5% occurred 313 yards along the 711 yards of tested rope-length. The test was started at the #2 skip rope end*.

The 0%LMA level was, correctly, placed.

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* to be consistent with Rotesco's 29.9.88 report, we refer to the rope end with the greater LMA as the skip #2 rope end, and the one with 0%LMA as the skip #1 rope end

The Magnograph operator submitted charts from two test set-ups. We attach copies of both, to illustrate the repeatability of these tests (Fig. 3). It will be noted that whenever we were unable to reproduce the full chart lengths in a single stretch, we provided match-marks (such as: ref.' A'; ref.' B'; etc.) on the individual chart segments. On reviewing the operator's charts, we accepted his LMA data as being correct.

The operator also reported LBS values of 19.6% at 174.5 yards from test start, and 13.9% at 600.5 yards. We attach copies of the relevant charts (Fig. 4), as marked up by the operator for his LBS calculations. Also these charts, obtained at increased chart-speeds, provide a better picture of rope conditions in the critical rope segments. We will describe the algorithm used by the operator for his LBS calculations in a later report.

The LMA-250 operator only submitted LMA data, without any LBS estimates. He reported — and marked on his chart (Fig. 5a) — a maximum LMA of 11.0%, some 228 ft along the 2,200 ft of tested rope length. Moreover, 7.0% LMA was marked some 1,090 ft from test start. The test was started at the #2 skip rope end. At first sight these chart-readings appear to be acceptable.

On reviewing, though, the LMA instrument chart (Fig. 5a) we noted that the operator placed the 0%LMA reference level some 1,690 ft along the tested rope length, ignoring the rise in his LMA chart trace as it approaches the 2,000 ft, i.e., the skip #1, rope end. This is an unfortunate error, as can be seen from the aforementioned Rotesco AC and Magnograph charts (Figures 1, 2, and 3), as well as from the yet to be discussed shop-floor test results (Table 1). In fact, the 0%LMA reference level is at the skip #1 rope end. In Fig. 5b we reset and respliced the LMA-250 chart accordingly. Even if we now ignore the final rise in the LMA chart-trace to level $\underline{2}$ — which we should not do, in view of the other available chart traces such as the corresponding shop-floor chart traces of the LMA-250 (Fig. 8) and of the Rotescograph (Fig. 9c) — and only set the 0%LMA reference level a distance $\underline{1}$ above the operator's original 0%LMA level, we still have to add another 15.0% LMA to his chart-readings. But instead of the reported 11.0%, this results in an incredible 26.0% LMA_{max}, which we cannot accept. In view of the other results (Table 1) we suggest that, apart from mistakenly locating the 0%LMA reference some 1,690 ft along the rope, the operator also mis-recorded his instrument's actual LMA-gain setting. We reported a similar situation previously (6). As in the previous case, we believe that the chart readings should be, at least, halved. In other words the operator's reported LMA_{max} of 11.0% should, in fact, be in the order of $(11.0 + 15.0) \times \frac{1}{2} = 13.0\%$. Had a calibration wire been taped to the rope, the foregoing uncertainty could have been avoided.

SHOP FLOOR TEST RESULTS — AS REPORTED AND REVIEWED

General procedure

The shop-floor tests were undertaken with a Rotesco AC, a Magnograph, a Rotescograph, an LMA-250, and with the prototype version of the latest German WBK instrument. None of the operators knew about each other's results before these were submitted to us. All details of the testing process were described, and illustrated, elsewhere (5).

At this time we have not, as yet, received the German test results. We shall publish these later, as soon as they become available.

The Rotesco AC data

The Rotesco AC data were obtained on 3.4.89, a day before the permanent magnet instruments were used. This was done to ensure proper rope demagnetization. We juxtapose the shop-floor instrument chart (Fig. 6a) and the in situ chart (Fig. 2a) on the same report page for easy comparison of the two. In each case testing started at the skip #2 rope end.

The seizing wire markers show up well. In Fig. 6 they are identified by the symbol 'M'. The symbol 'S/V' stands for "Speed Variation".

Although the shop-floor operator, quite correctly, set the 0% LMA reference level at the 2,070 ft (i.e., skip #1) rope end of his run, he incorrectly reported the LMA_{max} to be 7.4% some 75 ft from the test start. We realigned and respliced (Fig. 6b) his test chart, and juxtaposed it along the in situ chart (Fig. 2b): (a) for easy comparison of the two, and (b) to show that, in fact, the LMA_{max} shop-floor chart reading is only 5.4%, with a corresponding LBS_{max} of some 8.2%.

The Magnograph data

The operator reported (report #89-286F) having tested a rope length of 1,930 ft (Fig. 7). The seizing wire markers, on a 250 ft spacing, showed up well. In Fig. 7 they are identified by the symbols 'Mk 250 pi'; 'Mk 500 pi'; etc. Testing started at the skip #2 rope end. The 0%LMA reference level was, correctly, placed at the opposite, i.e.,

skip #1, rope end. An LMA_{max} of 11.0% was reported some 708 ft along the tested rope. The LBS_{max} was reported to be 28.5% some 290 ft from test-start.

After reviewing the reported data, we accepted them.

The LMA-250 data

The operator reported having tested a rope length of some 2,120 ft (Fig. 8). The seizing wire markers, on a 250 ft spacing, showed up well. They are identified by symbols 'M1'; 'M2'; etc. in Fig. 8. Testing started at the skip #2 rope end. The 0%LMA reference level was placed correctly. An LMA_{max} of 15.0% was read off the chart at marker M5, i.e., some 1,200 ft along the tested rope. No LBS estimates were submitted.

After reviewing the reported data, we accepted them.

The Rotescograph data

The operator tested some 2,194 ft of rope on 5.4.89 (Fig. 9a) and 2,246 ft on 10.4.89 (Fig. 9b). Both tests started at the skip #2 rope end. The seizing wire markers, on a 250 ft spacing, showed up well. The operator identified them by writing "Marker" on his chart. The operator did not submit a report on his 5.4.89 tests. Nor did he mark up his corresponding chart. We added the 100% reference level and the LMA_{max} value to Fig. 9a ourselves. For his 10.4.89 test run, though, he reported, and marked on his chart (Fig. 9b), an LMA_{max} of 10.0% at 370 ft from test start (with a corresponding LBS_{max} of 20.0%).

While a constant chart-speed was maintained during the 5.4.89 test run, the speed was increased twice during the 10.4.89 test. According to the operator's chart markings (Fig. 9b), the chart-speeds were 1 mm/sec; 10 mm/sec; and 25 mm/sec. However, on checking the corresponding speed ratios on the basis of the distance markings along the chart-edge, we find that this can not be correct. The medium:slowest; fastest:medium; and fastest:slowest speed rations are, in fact, 4.2; 2.3; and 10.0. On measuring the overall chart lengths, and considering the known average rope-speeds used (in the order of 50–70 ft/min), we believe the actual chart-speeds were, very likely, in the order of: 1 mm/sec; 5 mm/sec; and 10 mm/sec. On 5.4.89 the chart-speed seems to have been maintained at 1 mm/sec.

It is interesting to see details of the LF trace at the increased chart-speeds of the 10.4.89 test run. There appears to be no evidence of any broken wires.

The operator correctly assigned the 0%LMA reference level to the 2,246 ft (i.e., to the skip #1) rope end. Unfortunately, though, he ignored the final LMA trace rise. He also erred in reporting a 10.0% LMA_{max} at 370 ft from test start. We realigned and respliced the relevant chart sections (Fig. 9c). As can be seen, the LMA_{max} at the 373 ft location, as also at a few other locations, is actually 8.2%. In line with the operator's own method of calculation, we doubled the respective LMA chart-readings to obtain the corresponding LBS estimates.

COMPARISON OF IN SITU AND SHOP FLOOR CHARTS

The Rotesco AC results

We found the in situ LMA chart readings to be correct. Even with an increase from 1.3% LMA_{max} in March, 1988, to 4.0% LMA_{max} in September, 1988, it was surprising to note that by the time the Magnograph chart was obtained less than a month later, the LMA chart-reading should again have more than doubled. In this context we would point to the much lower LMA_{max} value of the Rotesco AC instrument on the shop-floor, than the equivalent ones of the Magnograph and LMA-250, although: (a) these were all obtained at the same time, and (b) they were not much different from their respective in situ counterparts.

The 3.4.89 Rotesco AC shop-floor reading was found to be in error.

On juxtaposing the in situ (Fig. 2b) and shop-floor (Fig. 6b) Rotesco AC instrument charts we note that their shapes are quite similar. Quantitatively too the results (Table 1) are comparable, despite the fact that the measurements were obtained more than six months apart, one in situ at relatively high rope speed and loading, and the other reel-to-reel at relatively low rope speed and tension. Moreover, different instruments and operators were involved, as well as rough rope handling in between the two tests.

The Magnograph results

We accepted both the operator's field-test, as well as his shop-floor reports. As with the Rotesco AC, the field and reel-to-reel test results are very close (Table 1). They are, however, more than double the Rotesco AC's chart readings.

The same operator and instrument was used for both the in situ and shop-floor tests. Otherwise, though, conditions differed widely, as in case of the Rotesco AC measurements.

The LMA-250 results

We could not, unfortunately, accept the in situ test-report without major modifications. In our opinion the mistakes were due to a misplaced 0%LMA reference level on the LMA instrument chart, and to a mis-recorded LMA-gain setting.

We agreed with the reel-to-reel test report's LMA chart readings.

No LBS estimates were supplied in either case.

DESTRUCTIVE TESTING

Three 16-ft samples were cut from our rope #5 for destructive testing. Of these 8-ft samples were used for destructive testing, and 8-ft ones for external and internal visual inspection. Results of the latter work are not available as yet.

The general test procedure was described, and illustrated, elsewhere (6).

The samples were designated as sample #5a, #5b, and #5c. With reference to Fig. 7:

Sample #5a: cut from the skip #1 rope end, i.e., from the "best" rope section;

Sample #5b: cut from the 11.0% LMA_{max} rope section, location 708 ft from test start, i.e., from the "worst" rope section;

Sample #5c: cut approximately 260 ft from test start, i.e., from a rope section with large LF trace amplitudes and an LMA of some 10.0%.

Destructive testing was performed in the laboratories of Wire Rope Industries (WRI) Ltd., at Pointe Claire, Quebec. It was monitored by Messrs. G. Rousseau (from CANMET) and R. Bole (from WRI). Standard procedures were followed.

As mentioned before, the original breaking strength of rope #5 was determined by the Rope Testing Laboratory of the Ontario Ministry of Labour, in Toronto. According to their test certificate #65926 of 30.1.86 it was found to be 274,800 lb. The destructive test results were as follows:

Sample #5a: 278,000 lb, i.e., an increase of 1.2% over the original strength, at a point where the LMA chart reading is 0.0% (Fig. 7);

Sample #5b: 245,000 lb, i.e., a decrease of 10.8% in the original strength, at a point where the LMA chart reading is 11.0% (Fig. 7);

Sample #5c: 245,000 lb, i.e., a decrease of 10.8% in the original strength, at a point where the LMA chart reading is 10.0% (Fig. 7).

The original nominal rope diameter was 1.4375 in. According to WRI's lab. report, all sample diameters were more than this value, ranging from 1.445 in. to 1.505 in.

Although the abovenoted "true" rope breaking strengths are more than had been estimated, and even more than the original breaking strength at the 0%LMA rope location, the rope was ready for removal. The destructive test results are misleading, insofar as they reflect the work hardened condition of this FLC head-rope. Consequently, they do not give an accurate picture of the remaining rope life. This phenomenon has been noted, and commented on, especially in case of FLC ropes, in previous CANMET reports (1, 6). Our present results confirm the necessity to measure rope extension, and the rotation resistance of individual wires, as well as the LBS values, in this, and similar cases.

The available photographs are reproduced in Fig. 10.

The condition of the broken samples was as follows:

Sample #5a: one outer wire, and several inner wires broke. The sample was in good condition, with a dry surface and no visible wear;

Sample #5b: four outer wires broke some 2 ft from the cone. There was heavy rust and a very visible wave on the outer surface. An internal condition was also indicated at sample centre. Moreover, the broken wires showed heavy pitting corrosion;

Sample #5c: ten outer wires broke, three at the sample centre and seven about 2 ft from the cone. There was heavy rust and a very visible wave on the outer surface. An internal condition was also indicated at sample centre. Moreover, the broken wires showed heavy pitting corrosion.

SUMMARY

We summarized details of the test-results in Table 1, and of the EM test set-ups in Table 2.

It will be noted that of the reports submitted by three different instrument operators in the field, we could agree only with two. Similarly, of the four different instrument operator reports submitted to us after the shop-floor tests, we could only accept two without major alterations. The mistakes were of human rather than instrument related origin. They were caused by misplaced 0%LMA reference levels on the LMA instrument charts, and by mis-recorded instrument LMA-gain settings. Had a calibration wire been taped to the rope during testing, these mistakes would, probably, have been avoided, or at least rectified.

The two acceptable field reports, namely the Rotesco AC and Magnograph ones, were based on tests dated less than a month apart. It is noted that the LMA_{max} obtained with the Rotesco AC progressed from 1.3% in March, 1988, to 4.6% in September, 1988, and then within a month to 10.0%, according to the subsequent Magnograph test. In other words a 250% increase between March and September, and another 120% from September to mid-October. A surprisingly rapid rate. It is also noted that the reel-to-reel test results, obtained with a Rotesco AC and a Magnograph instrument more than six months after the in situ tests showed little additional LMA. Consequently, the in situ and reel-to-reel test results are very comparable, as they were shown to be in earlier reports (6, 7). However, both in the field and on the shop-floor, the Rotesco AC's LMA chart readings are much less than those of the permanent-magnet Magnograph and LMA-250 testers. We believe this difference might be due to basic design differences, namely to the weak magnetic field of the former and the strong one of the latter testers.

As before (6) the Rotescograph's LMA chart readings are below those of the two other permanent-magnet testers. Moreover, the LMA_{max} chart readings of 5.4.89 are noticeably different from those of 10.4.89, as they were seen to be in a previously reviewed case (6). This is, likely, due to some human error.

The difference between the LMA results of the various instruments is "unacceptably" large, insofar as it exceeds the ±2.0% range which we, and others, consider to be a reasonable limiting benchmark value (5, 8). Even the LMA_{max} chart-readings obtained with the LMA-250 and Magnograph instruments are at the very limit of the "acceptable" range.

Repeatability is again in evidence, as it was in all the other, previously reported cases (5, 6, 7). As an example we noted the similarity of the general shape of the various LMA chart-traces and, in particular, the consistency of the final rise in the LMA trace at the skip #1 rope end — in this respect note our remarks re. setting the 0%LMA level in Fig. 5b.

Without corollary rope-extension and wire rotation-resistance tests, the "true" LBS results are misleading, insofar as they reflect the work hardened rope conditions. Therefore, they do not give an accurate picture of the remaining rope life. This is a phenomenon that has been pointed out, especially in case of FLC ropes, in previous CANMET reports (1, 6).

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APPENDIX

Tables 1 and 2

as well as Figures 1 to 10, inclusive

Table 1

LMA_{max} chart readings and LBS_{max} estimates
Items 1–5: in situ tests; Items 6–10: shop-floor tests

Item No.	Test Instr.	As reported		As reviewed	
		LMA_{max}	LBS_{max}	LMA_{max}	LBS_{max}
1	Rotesco AC	0.7%	1.0%	0.7%	1.0%
2	Rotesco AC	1.3%	2.0%	1.3%	2.0%
3	Rotesco AC	4.0%	6.0%	4.6%	7.0%
4	Magnograph	9.0%	14.0%	10.0%	22.3%
5	LMA-250	11.0%	—	26.0%*	—
				13.0%**	—
6	Rotesco AC	7.4%	11.0%	5.4%	8.2%
7	Magnograph	11.0%	28.5%	11.0%	28.5%
8	LMA-250	15.0%	—	15.0%	—
9	Rotescograph	—	—	6.6%	13.2%
10	Rotescograph	10.0%	20.0%	8.2%	16.4%

*: with LMA-gain as reported by operator

**: with LMA-gain as reviewed by authors

Table 2

Details of EM testing of the 1 7/16 in. FLC rope

Item No.	Test Instr.	Test No.	Test date	Test location	Instr. operator*
1	Rotesco AC	DMP-89	1.10. 87	in situ	(1)
2	Rotesco AC	WMP-27	1.3.88	in situ	(1)
3	Rotesco AC	CBMP-13	29.9.88	in situ	(1)
4	Magnograph (two runs)	88-525B	19.10.88	in situ	(2)
5	LMA-250	—	21.10.88	in situ	(3)
6	Rotesco AC	—	3.4.89	shop-floor	(4)
7	Magnograph	89-286F	4.4.89	shop-floor	(2)
8	LMA-250	—	4.4.89	shop-floor	(5)
9	Rotescograph	—	5.4.89	shop-floor	(6)
10	Rotescograph	—	10.4.89	shop-floor	(6)

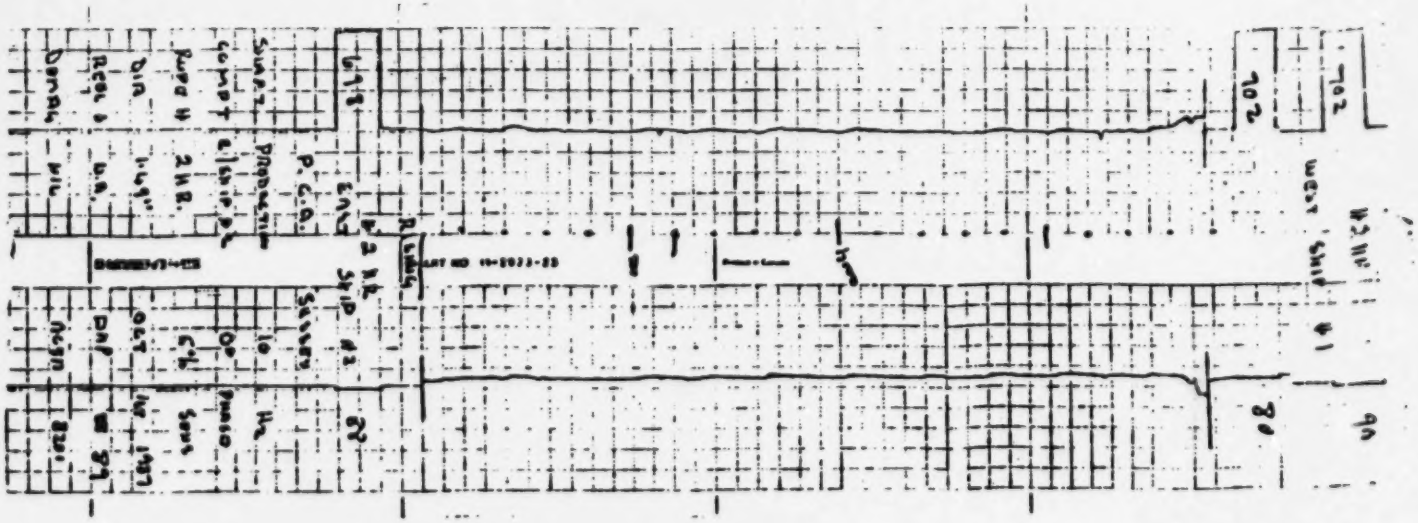
*: (1) and (3) instr. maker and service company

(2) service company

(4) and (6) mining company

(5) government organization

(a)



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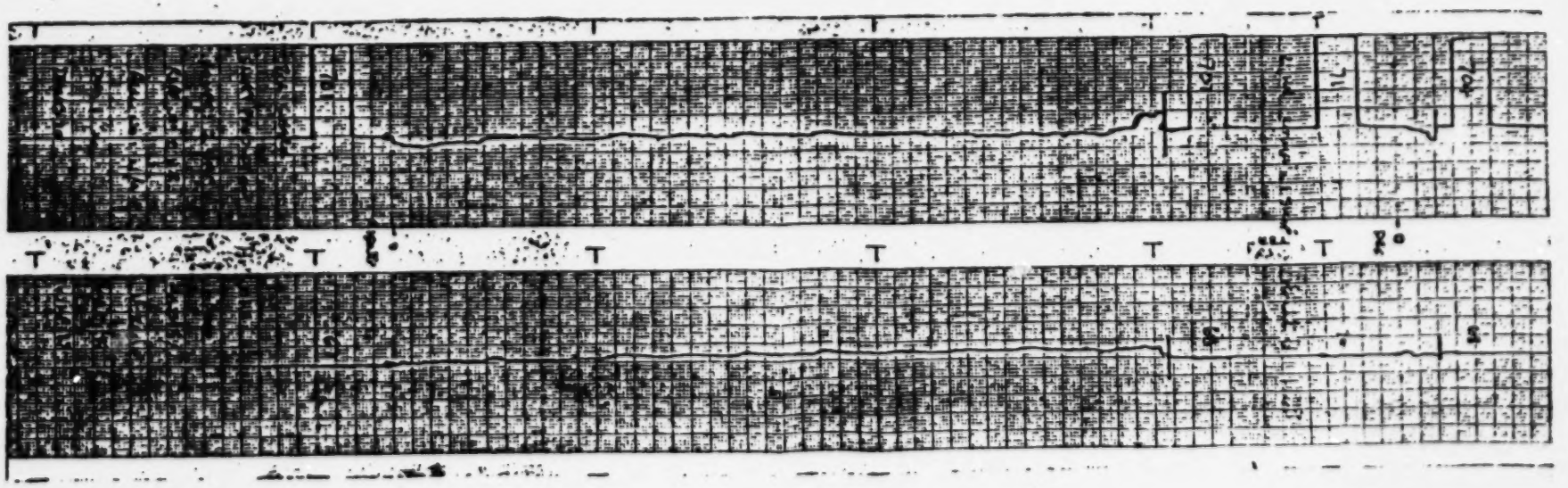

Fig. 1 — Rotesco AC in situ tests of: (a) 1.10.87, and (b) 1.3.88

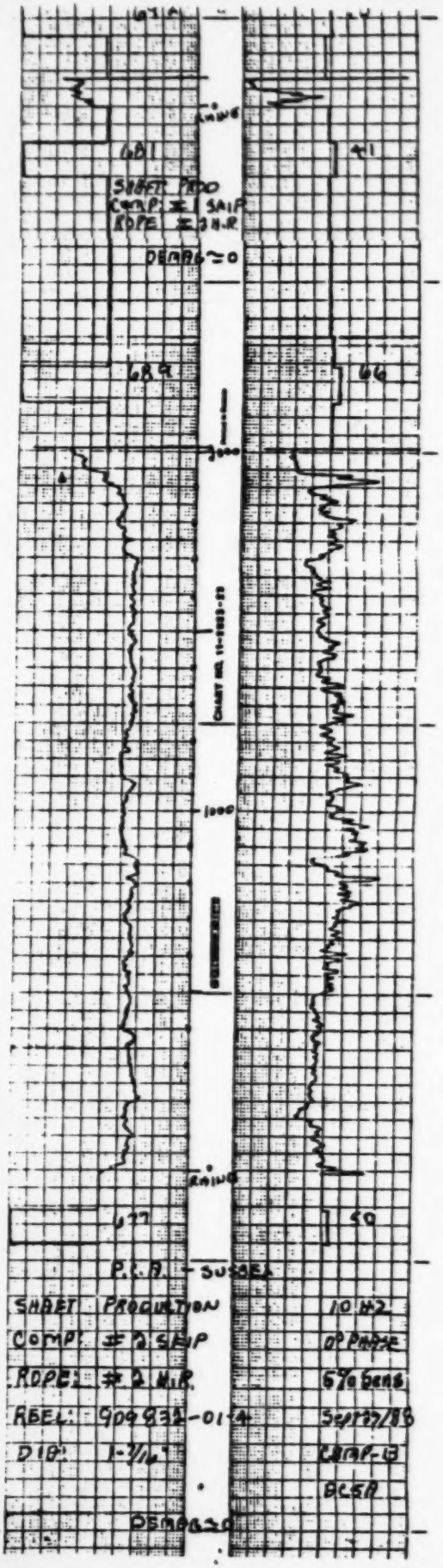

Fig. 2a — Rotesco AC in situ test of 20.9.88

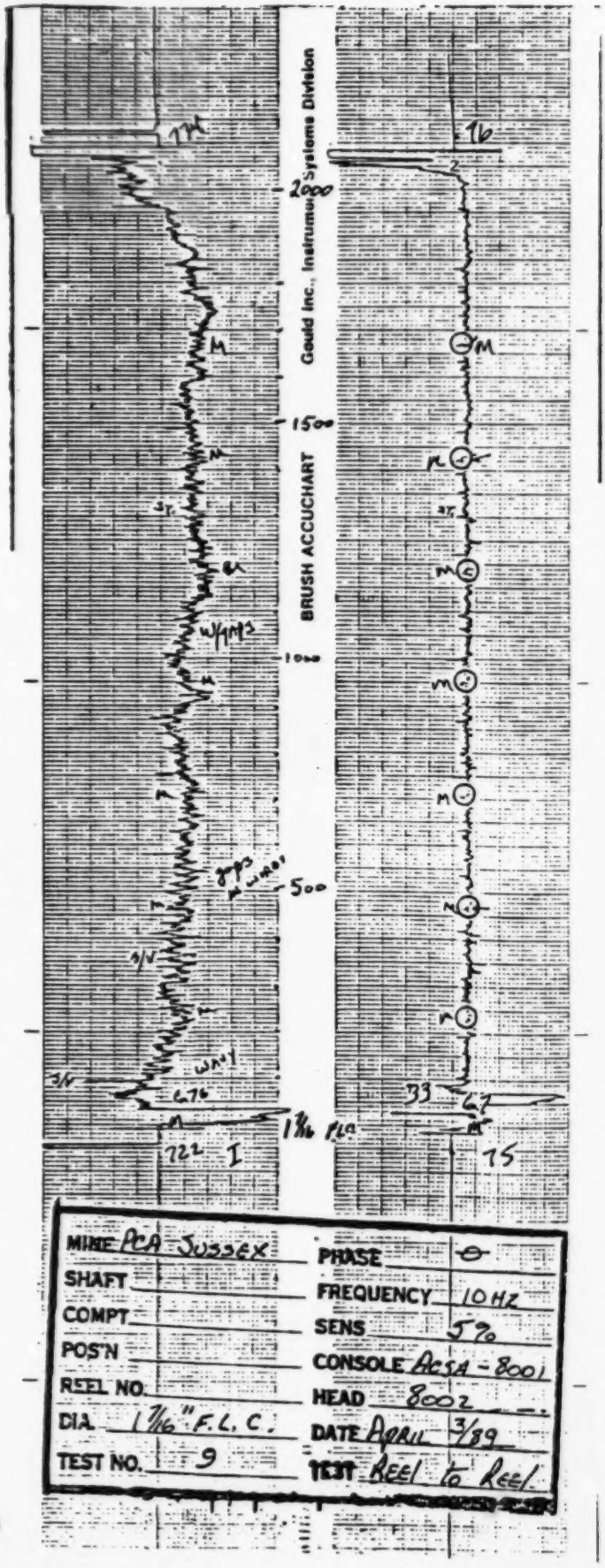

Fig. 6a — Rotesco AC shop-floor test of 3.4.89

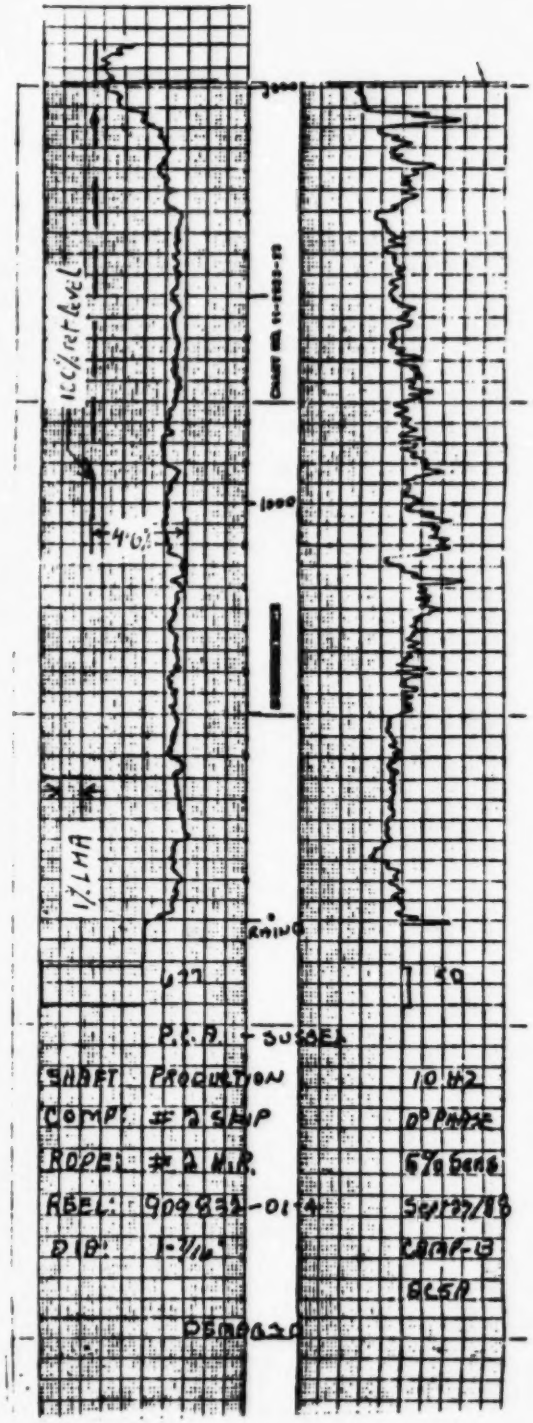

Fig. 2b — Rotesco AC in situ test of 20.0.88, as marked up by authors

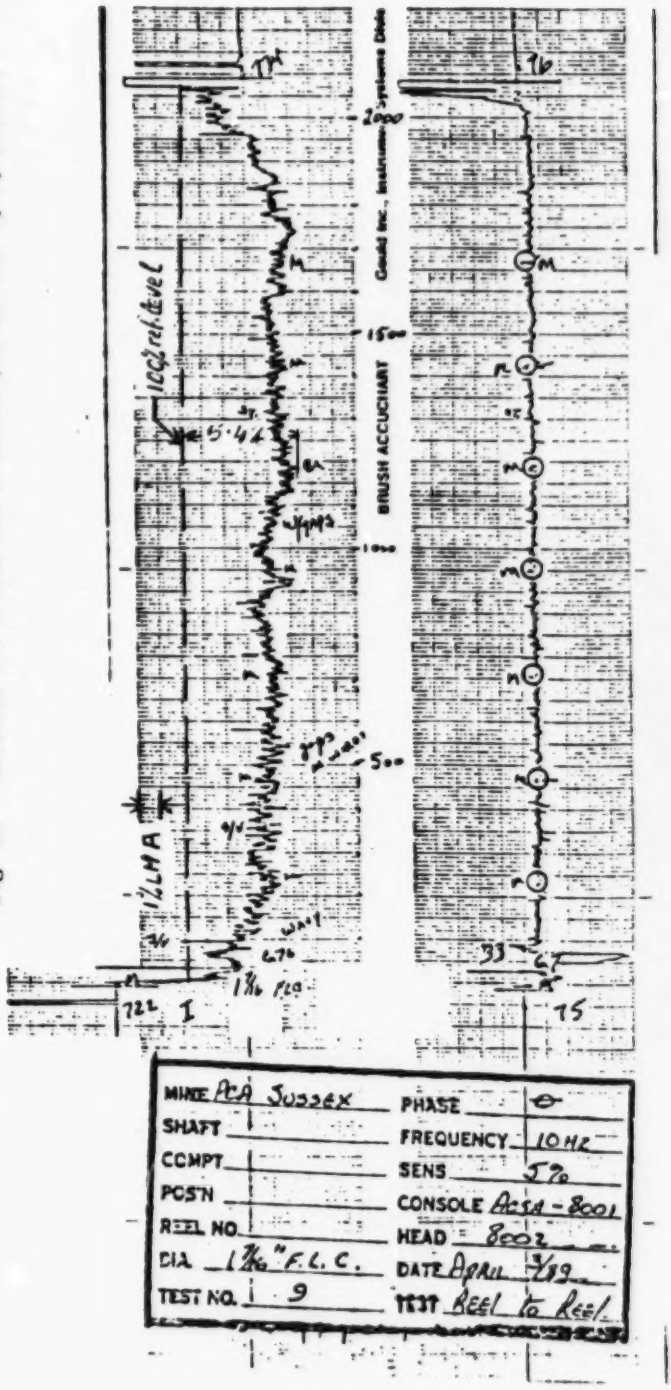

Fig. 6b — Rotesco AC shop-floor test of 3.4.89; as marked up by authors

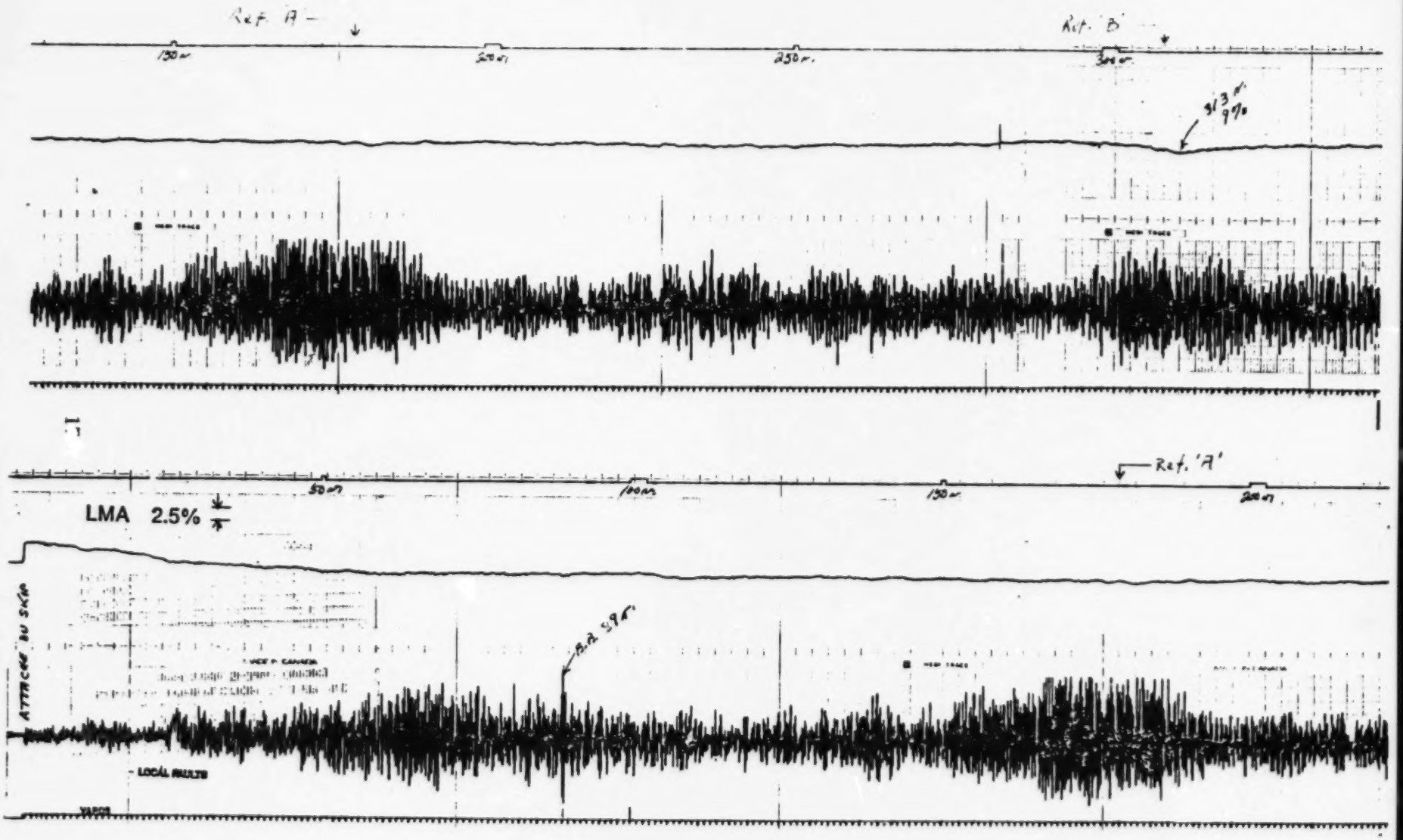

Fig. 3a — Magnograph in situ test of 10.10.88; test run #1

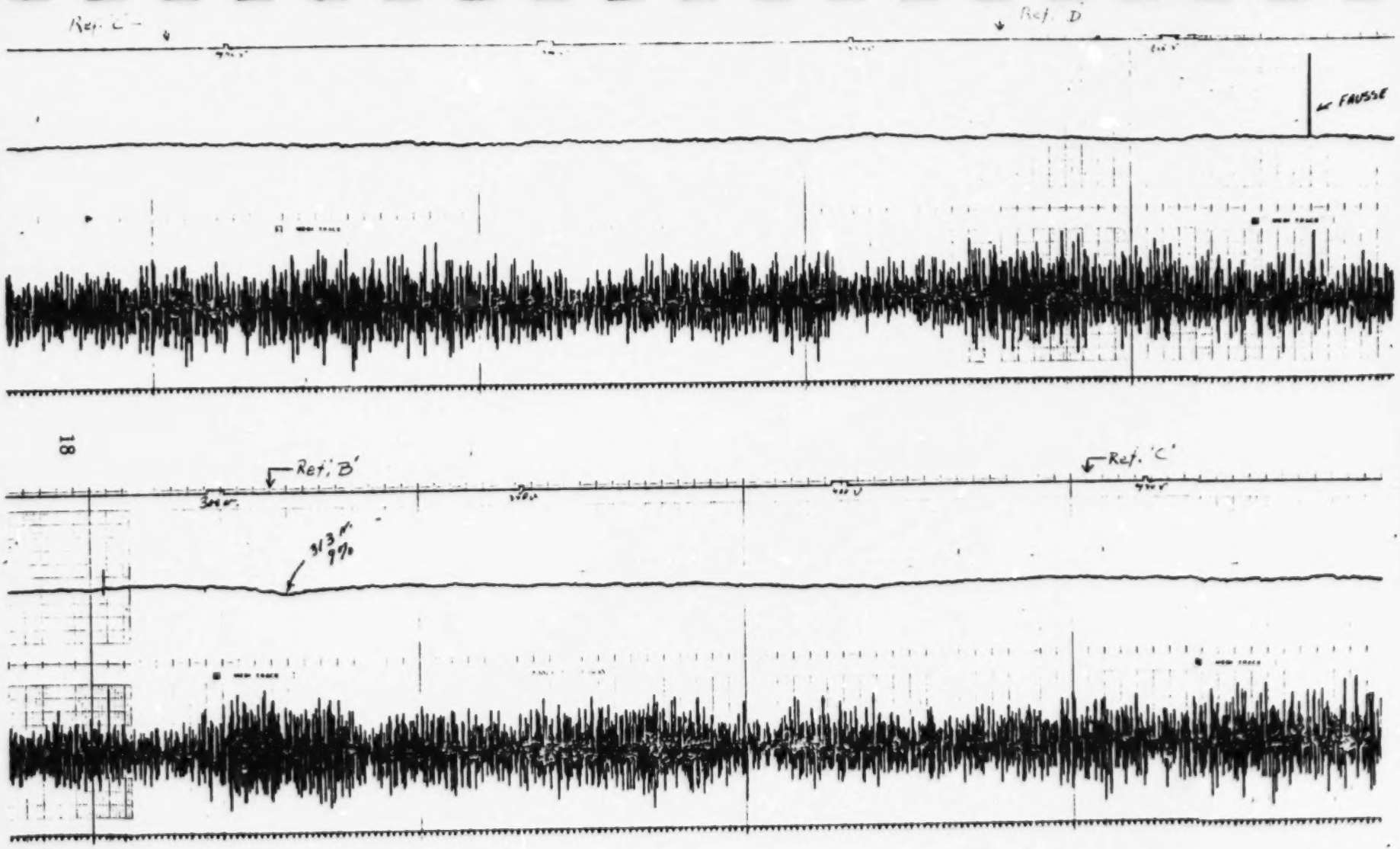

Fig. 3a (continued) — Magnograph in situ test of 19.10.88; test run #1

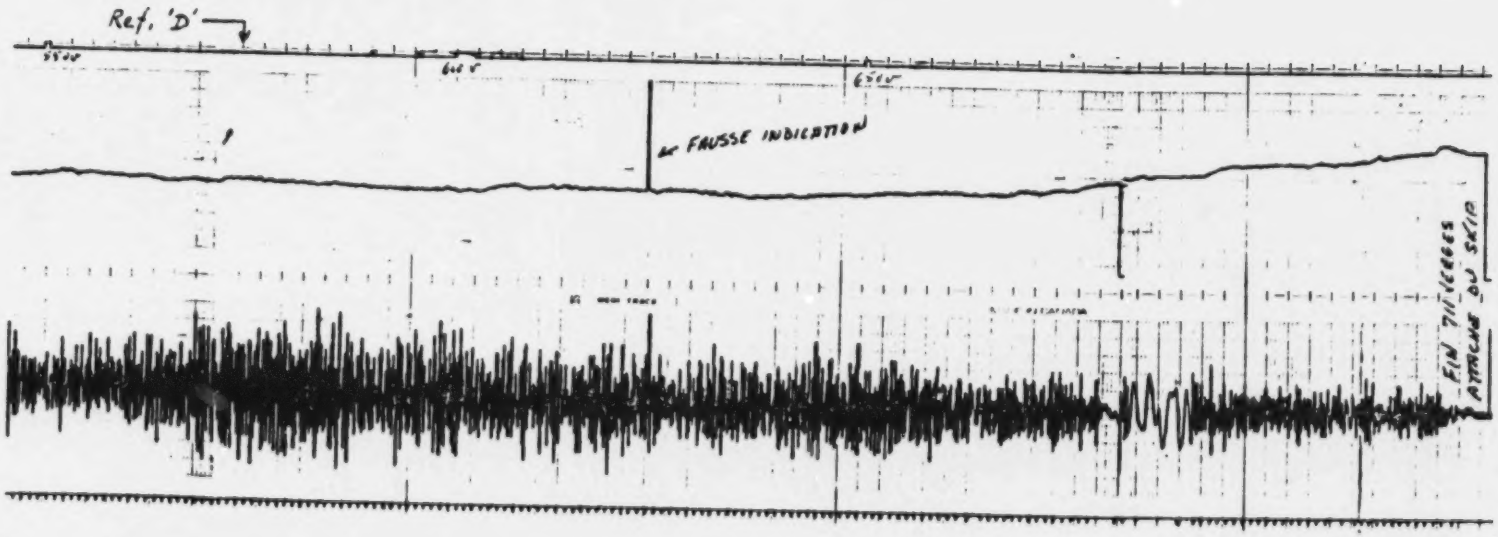

Fig. 3a (continued) — Magnograph in situ test of 19.10.88; test run #1

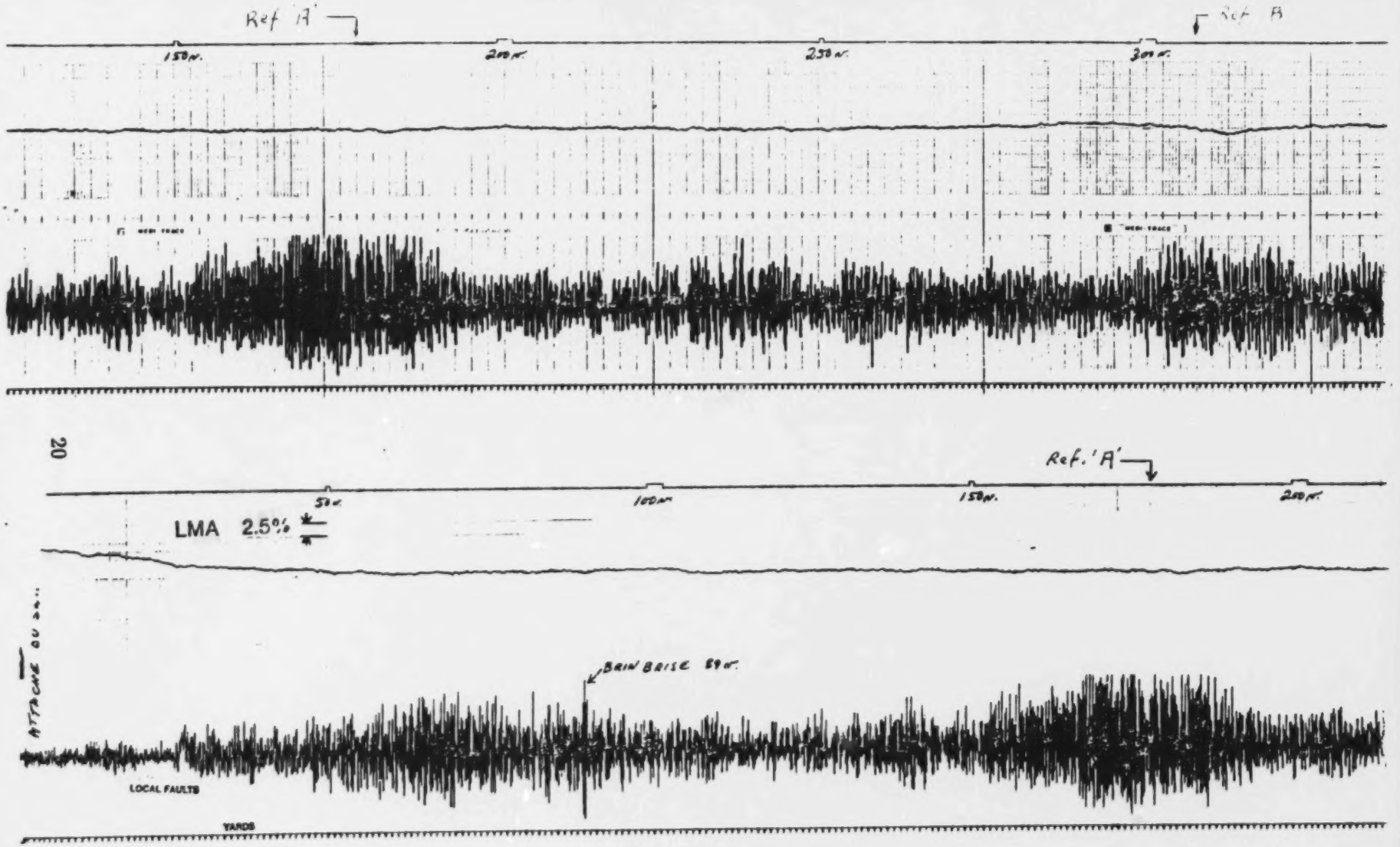

Fig. 3b — Magnograph in situ test of 19.10.88; test run #2

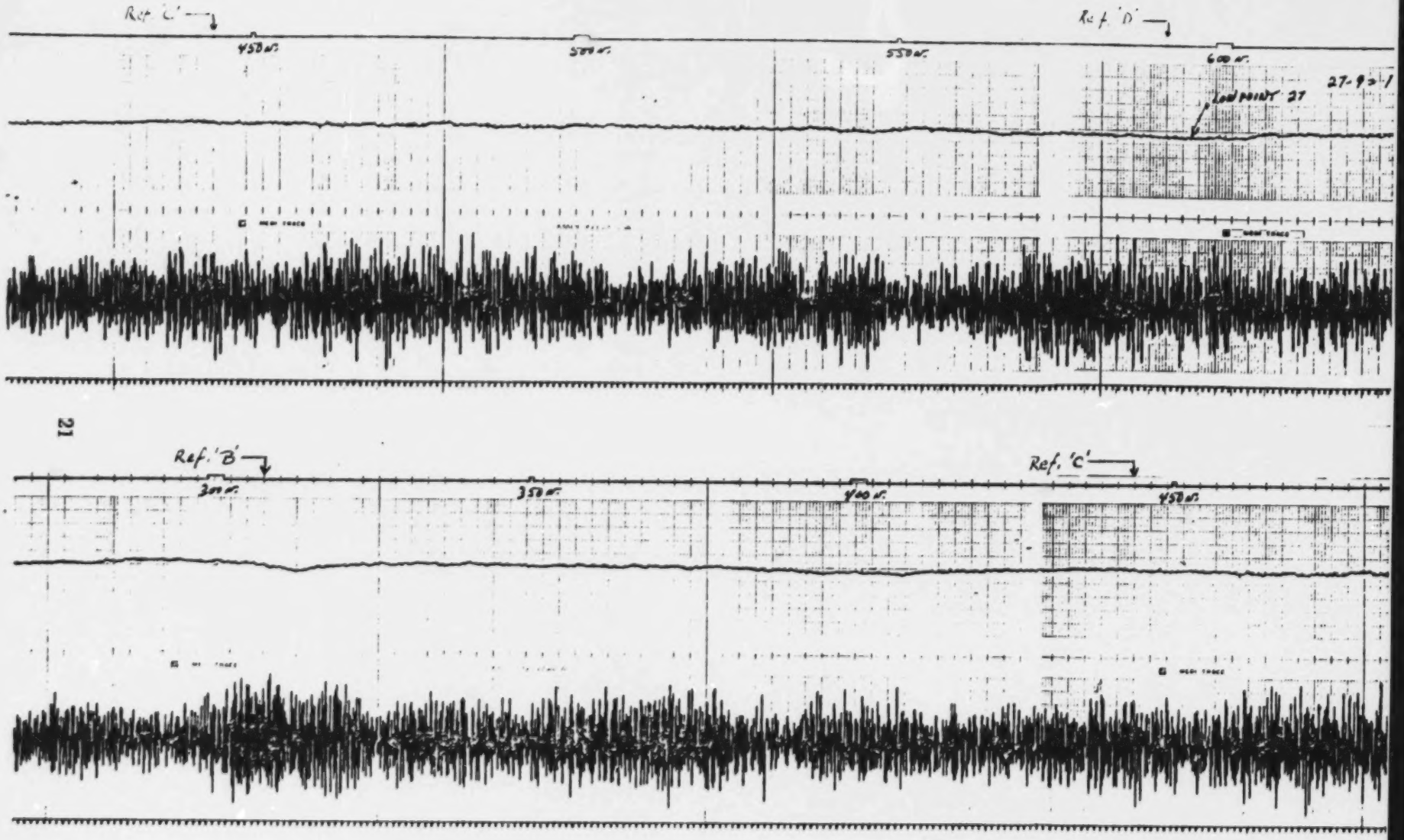

Fig. 3b (continued) — Magnograph in situ test of 19.10.88; test run #2

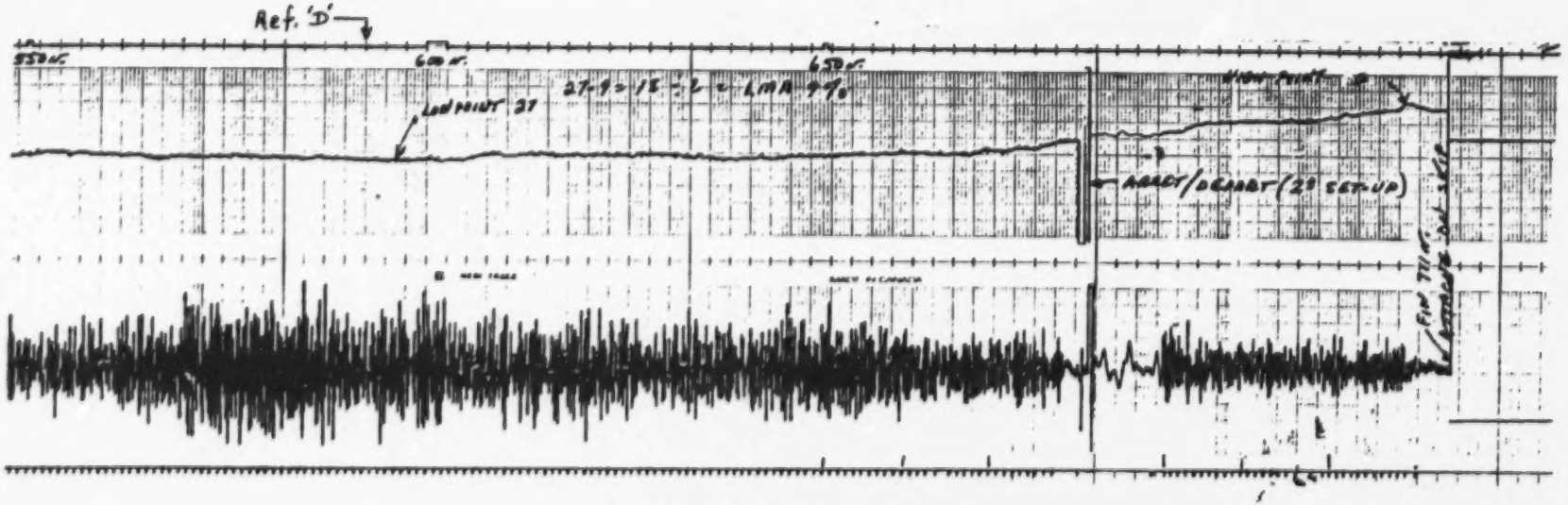

Fig. 3b (continued) — Magnograph in situ test of 19.10.88; test run #2

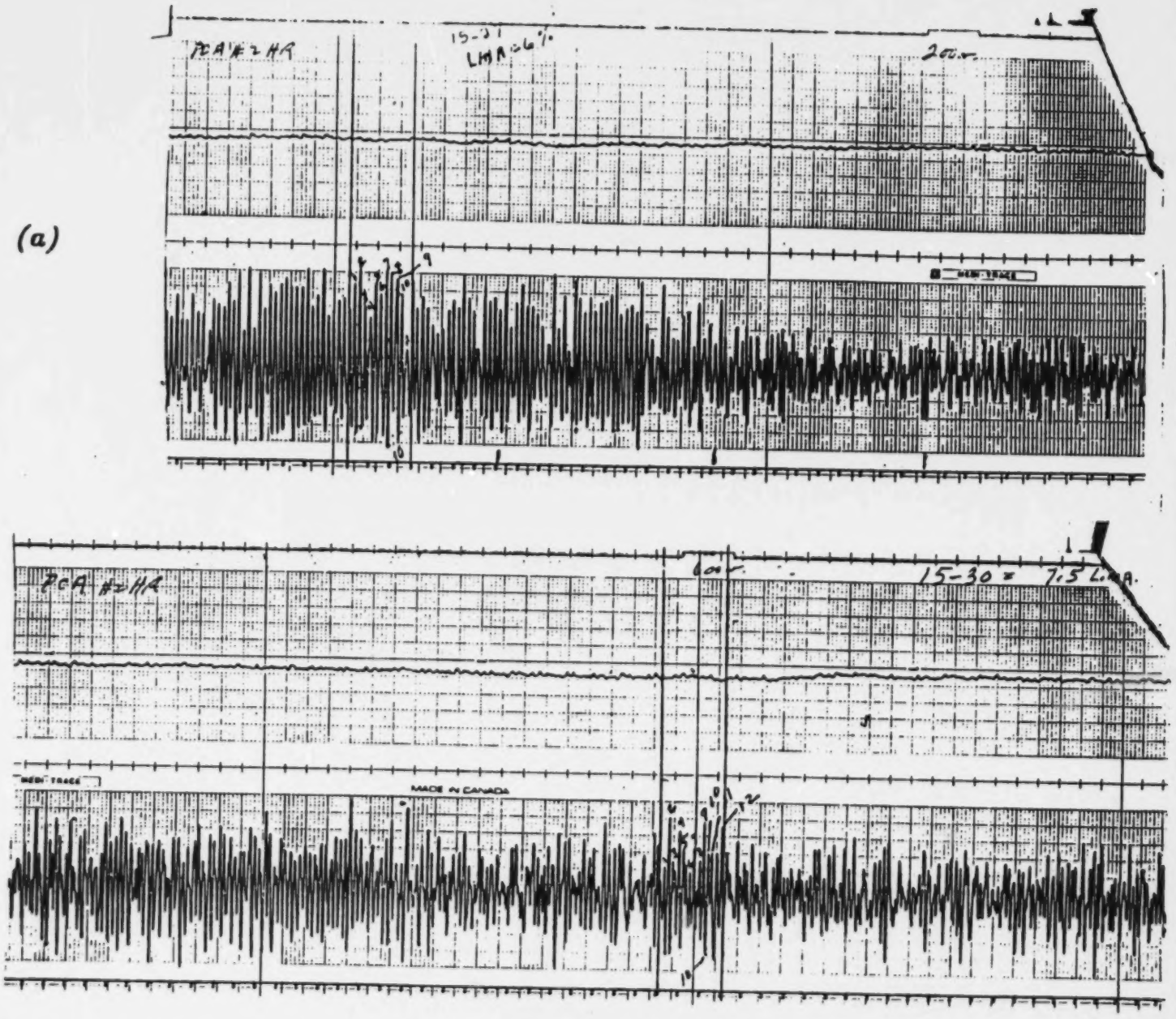

Fig. 4 — Magnograph in situ test of 19.10.88; expanded instrument charts for LBS calculations at: (a) 174.5 yards, and (b) 600.5 yards

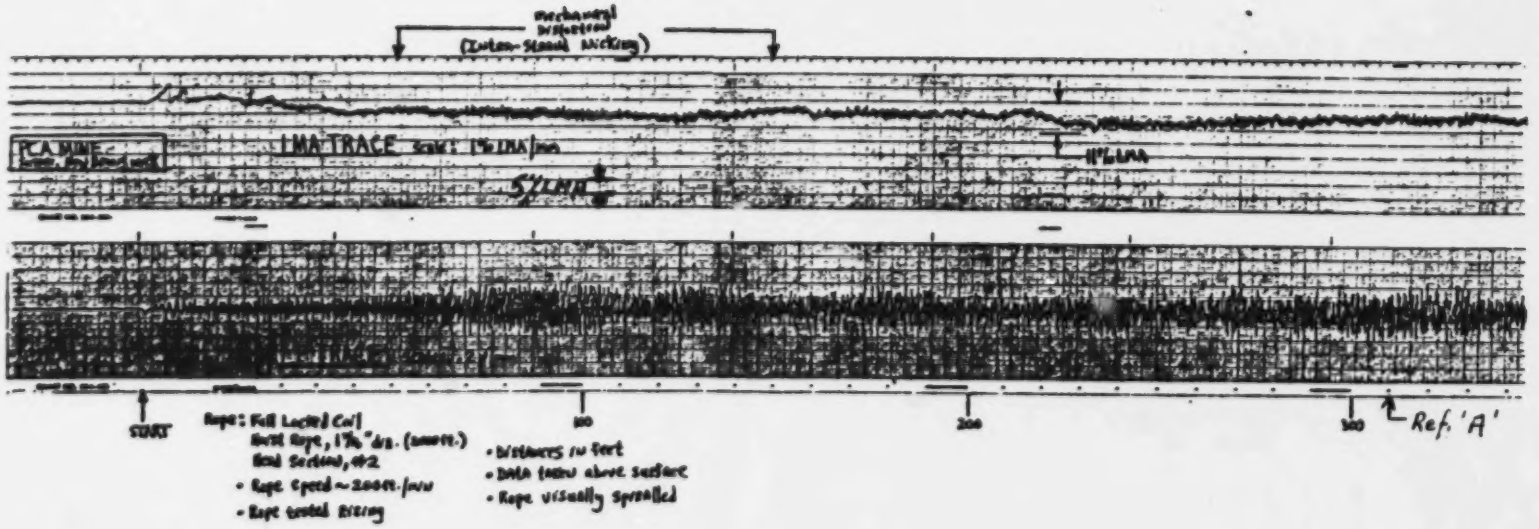

Fig. 5a — LMA-250 in situ test of 21.10.88

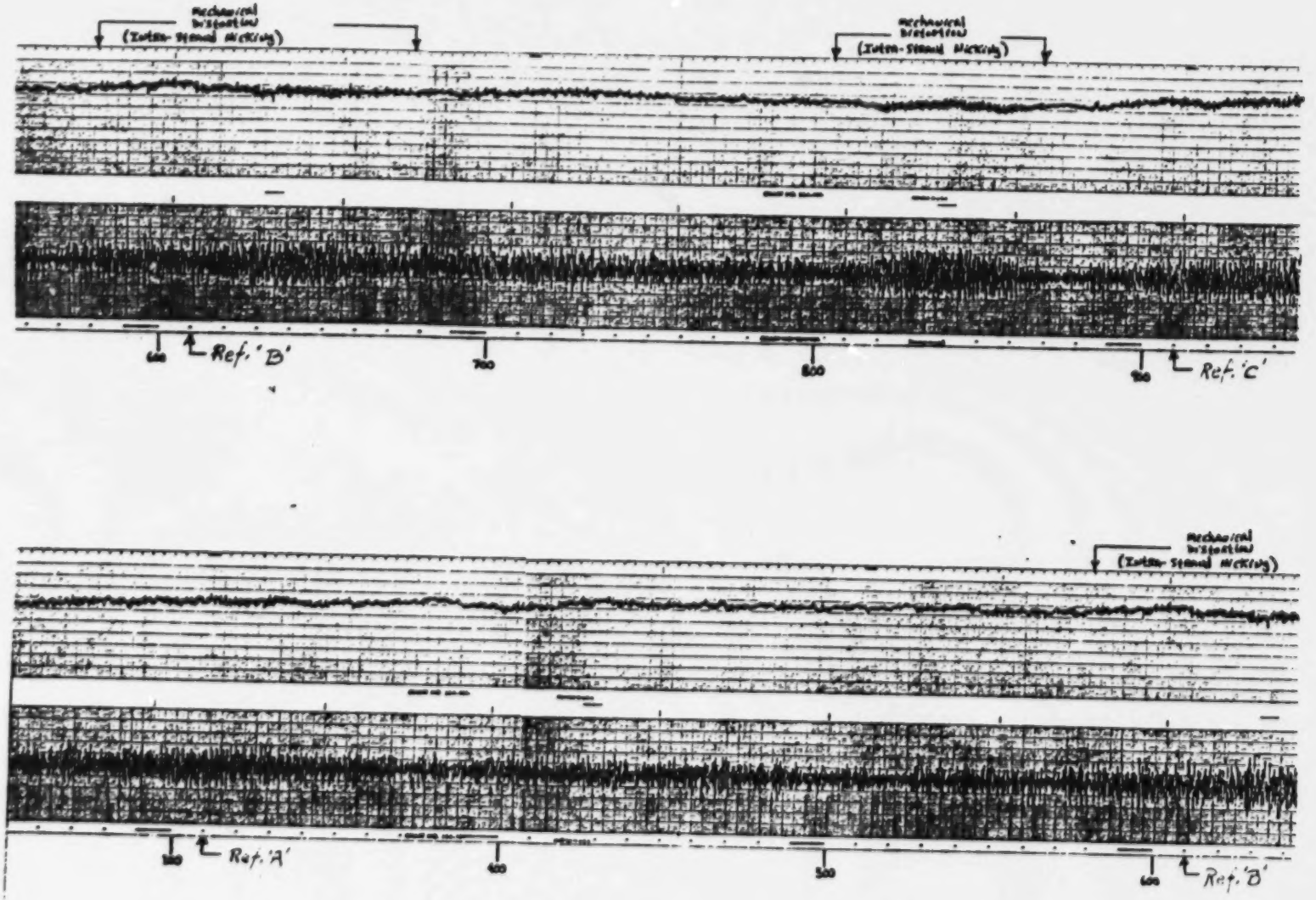

Fig. 5a (continued) — LMA-250 in situ test of 21.10.88

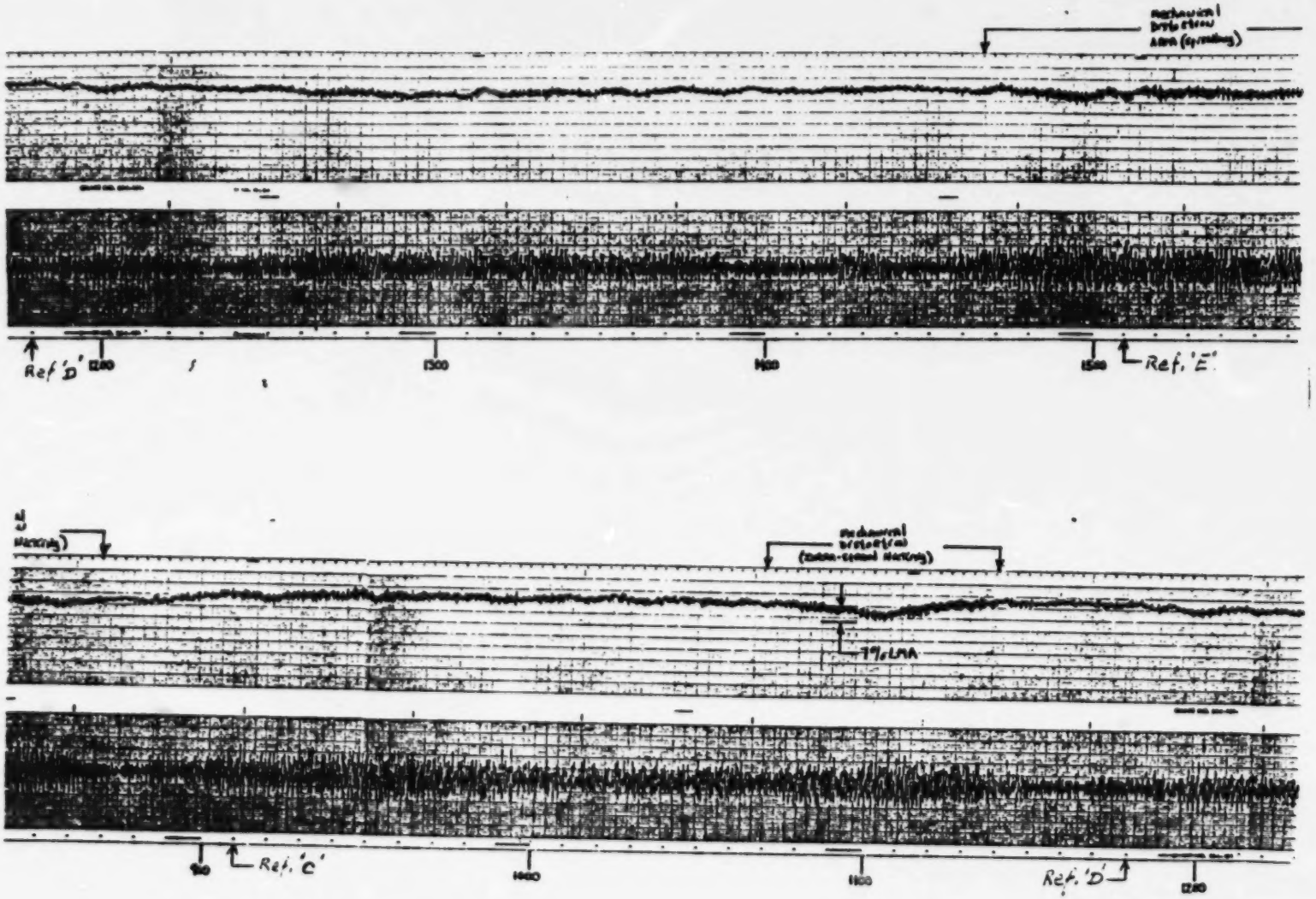

Fig. 5a (continued) — LMA-250 in situ test of 21.10.88

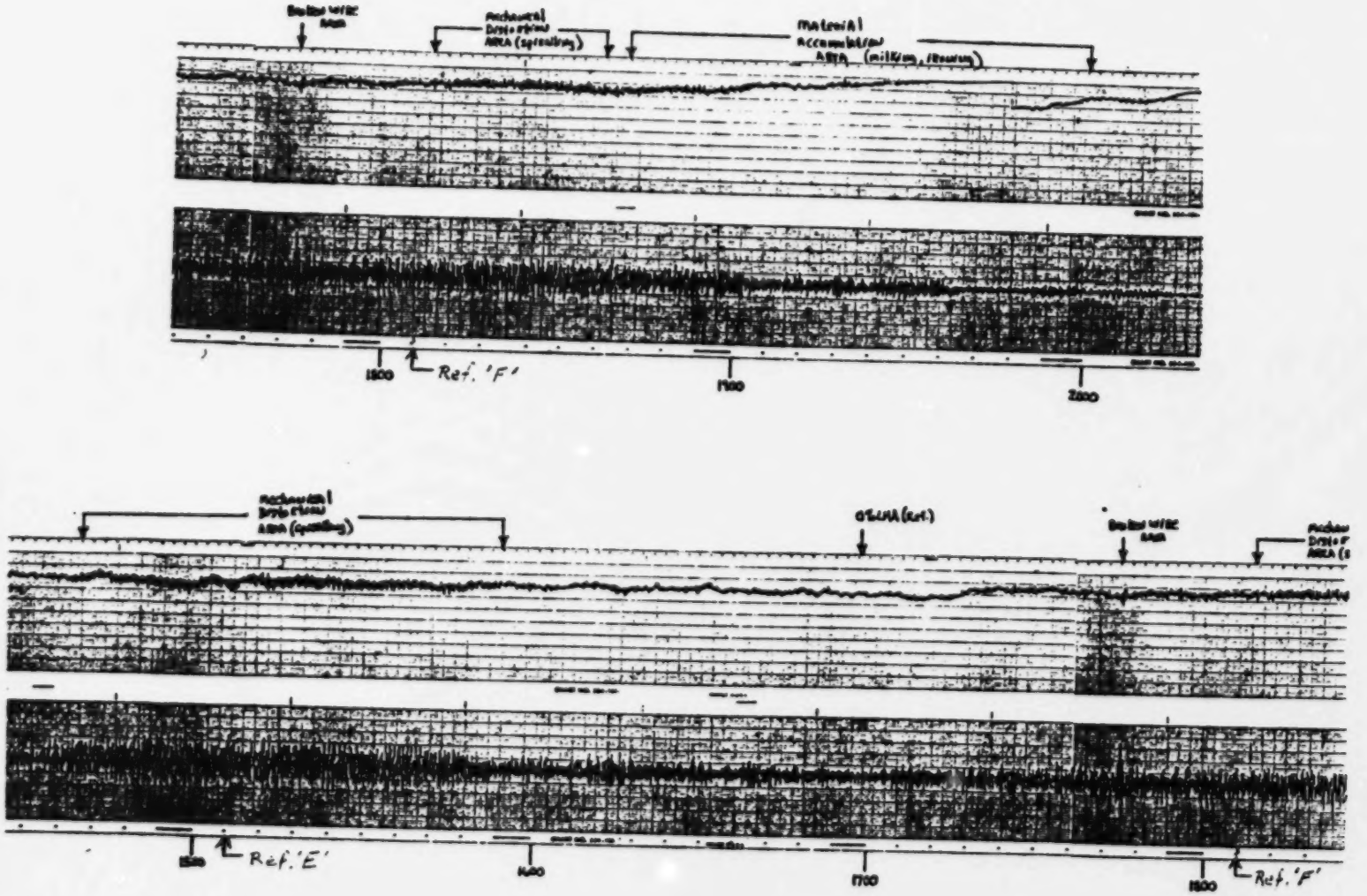

Fig. 5a (continued) — LMA-250 in situ test of 21.10.88

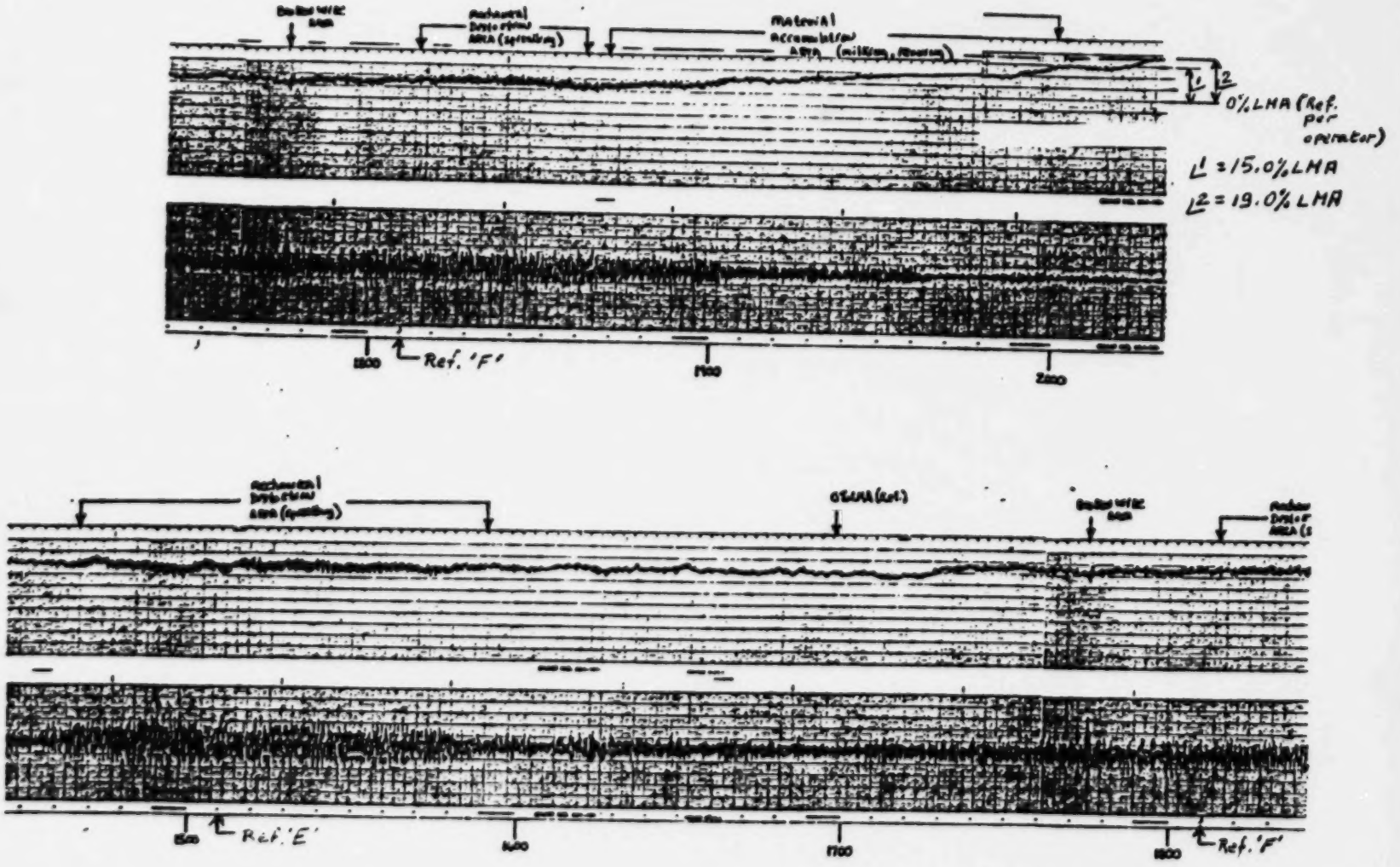

Fig. 5b — LMA-250 in situ test of 21.10.88; as marked up by authors

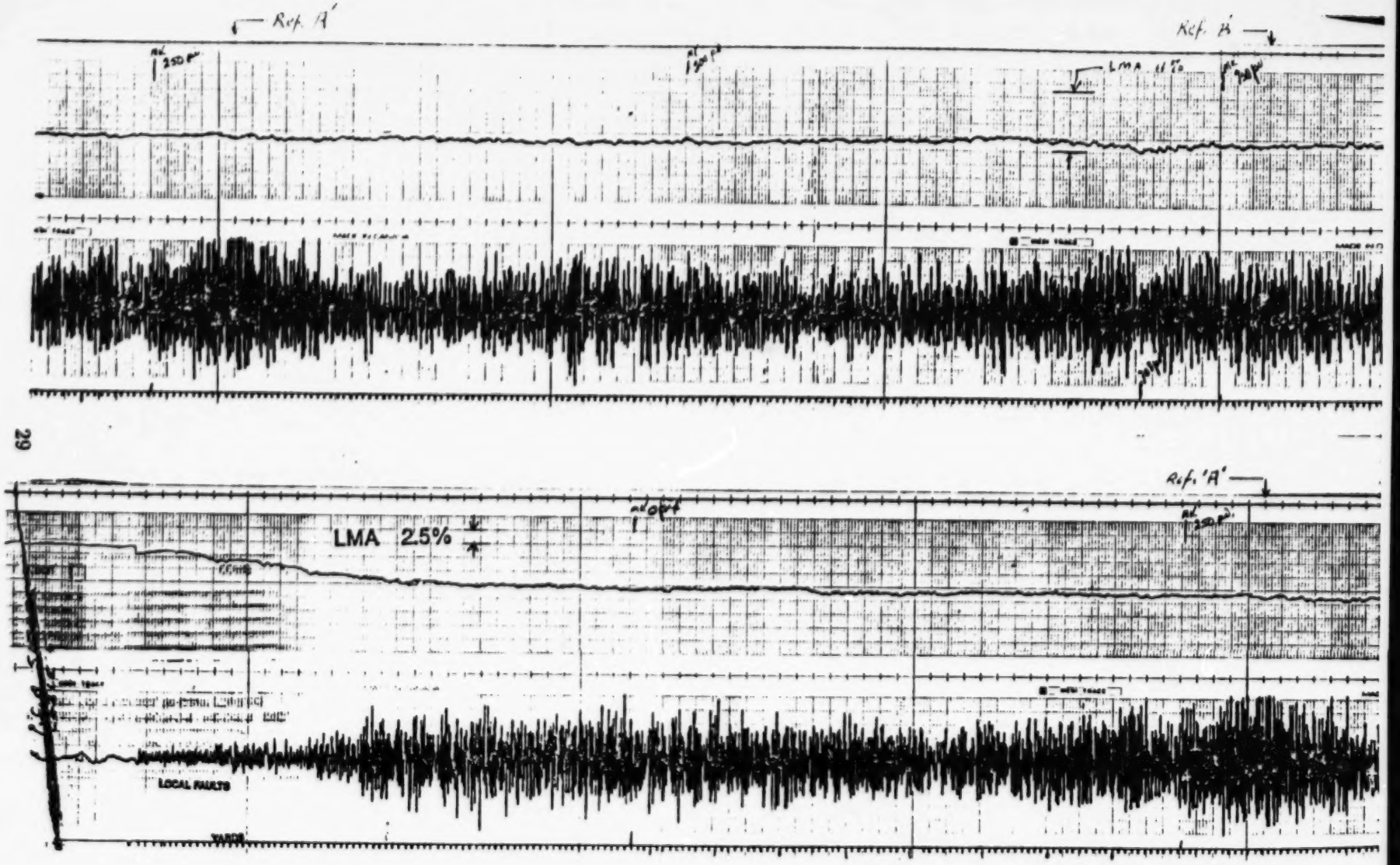

Fig. 7 — Magnograph shop-floor test of 4.4.89

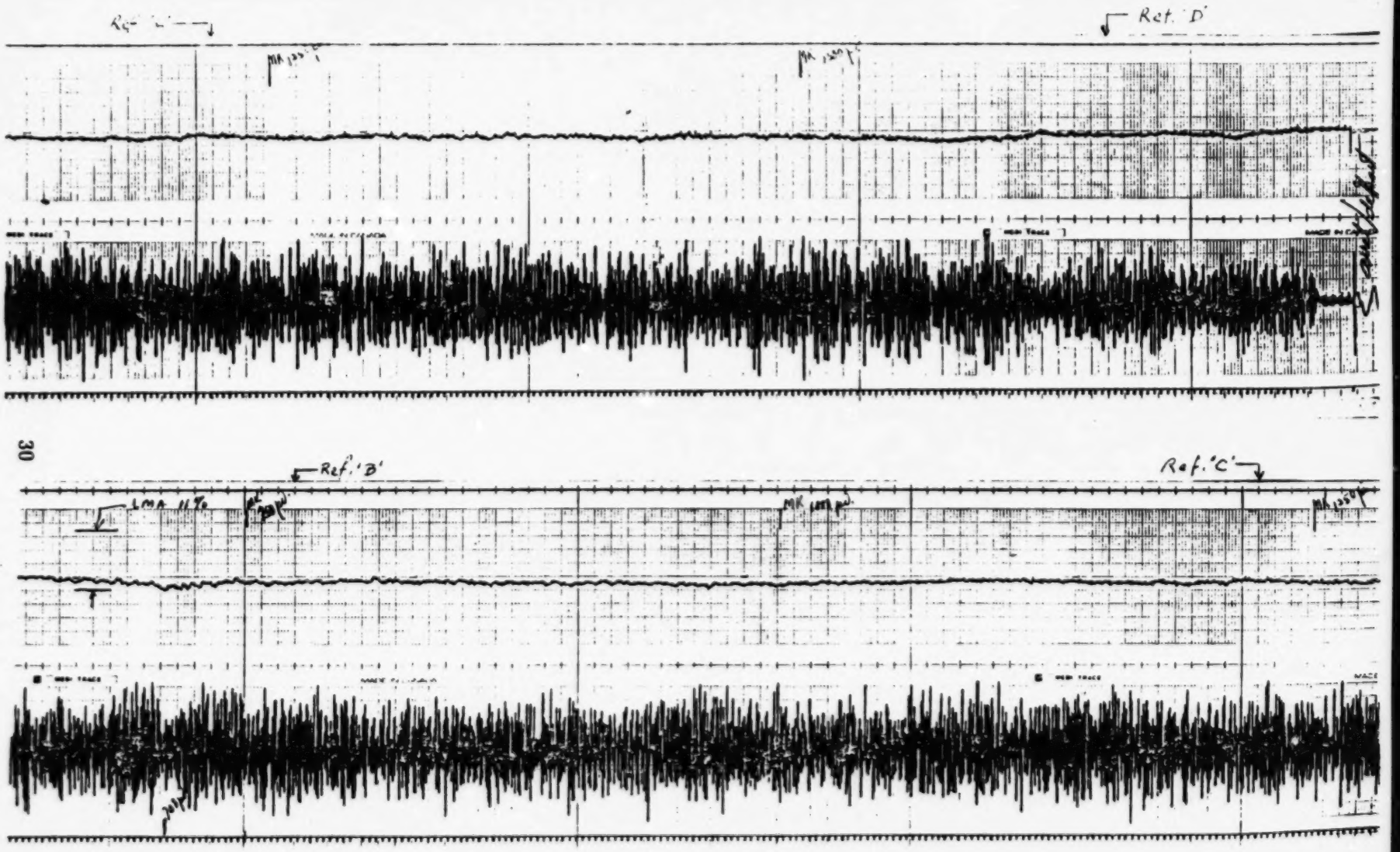

Fig. 7 (continued) — Magnograph shop-floor test of 4.4.80

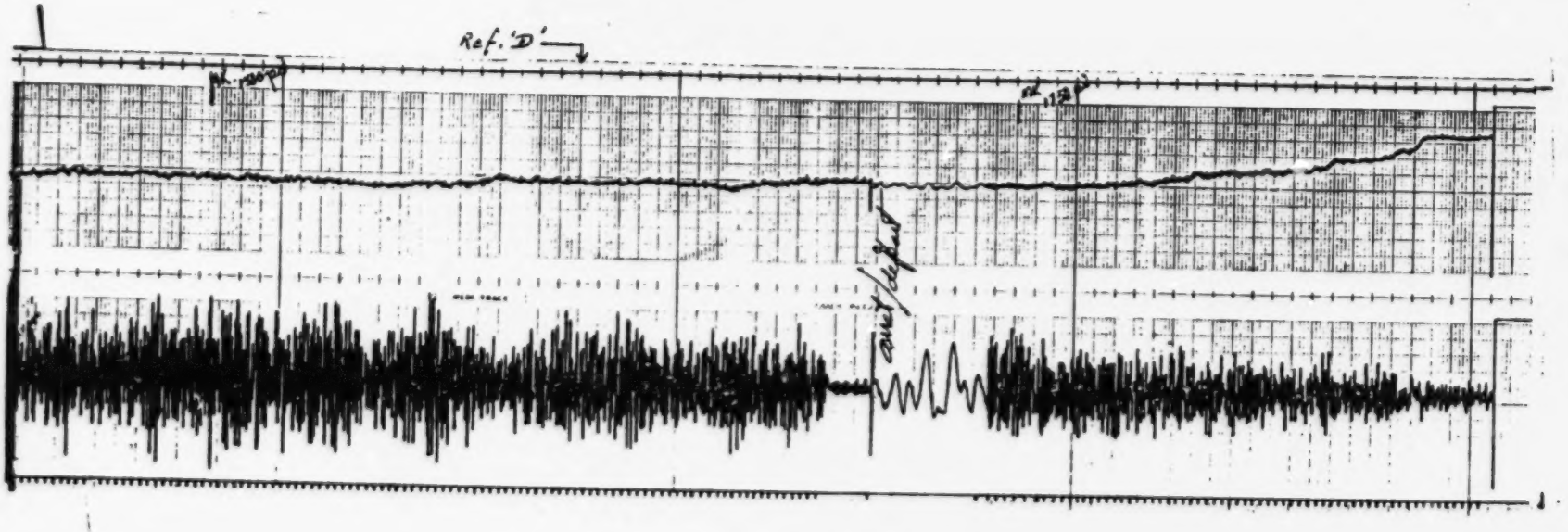

Fig. 7 (continued) — Magnograph shop-floor test of 4.4.89

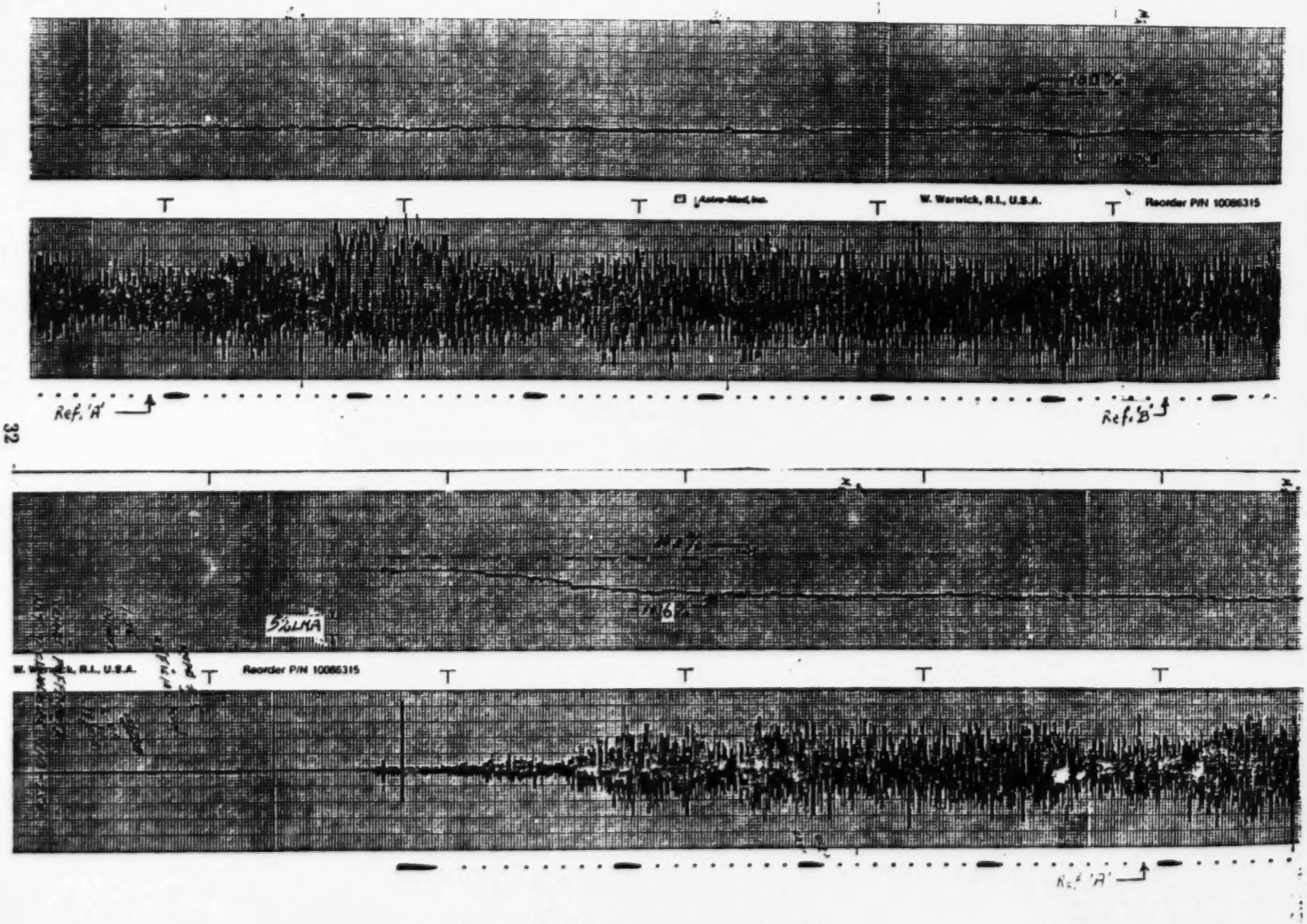

Fig. 8 — LMA-250 shop-floor test of 4.4.80

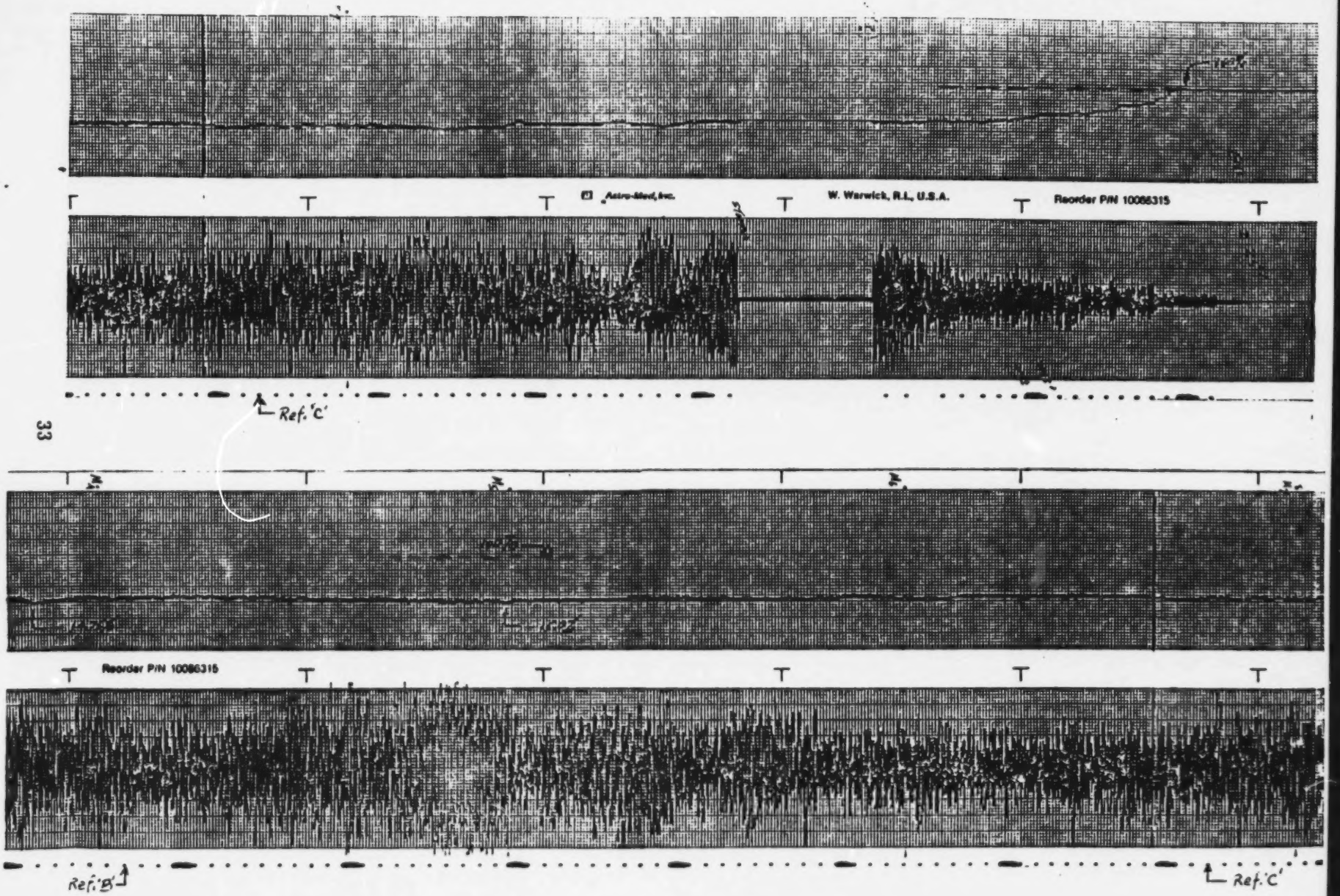

Fig. 8 (continued) — LMA-250 shop-floor test of 4.4.89

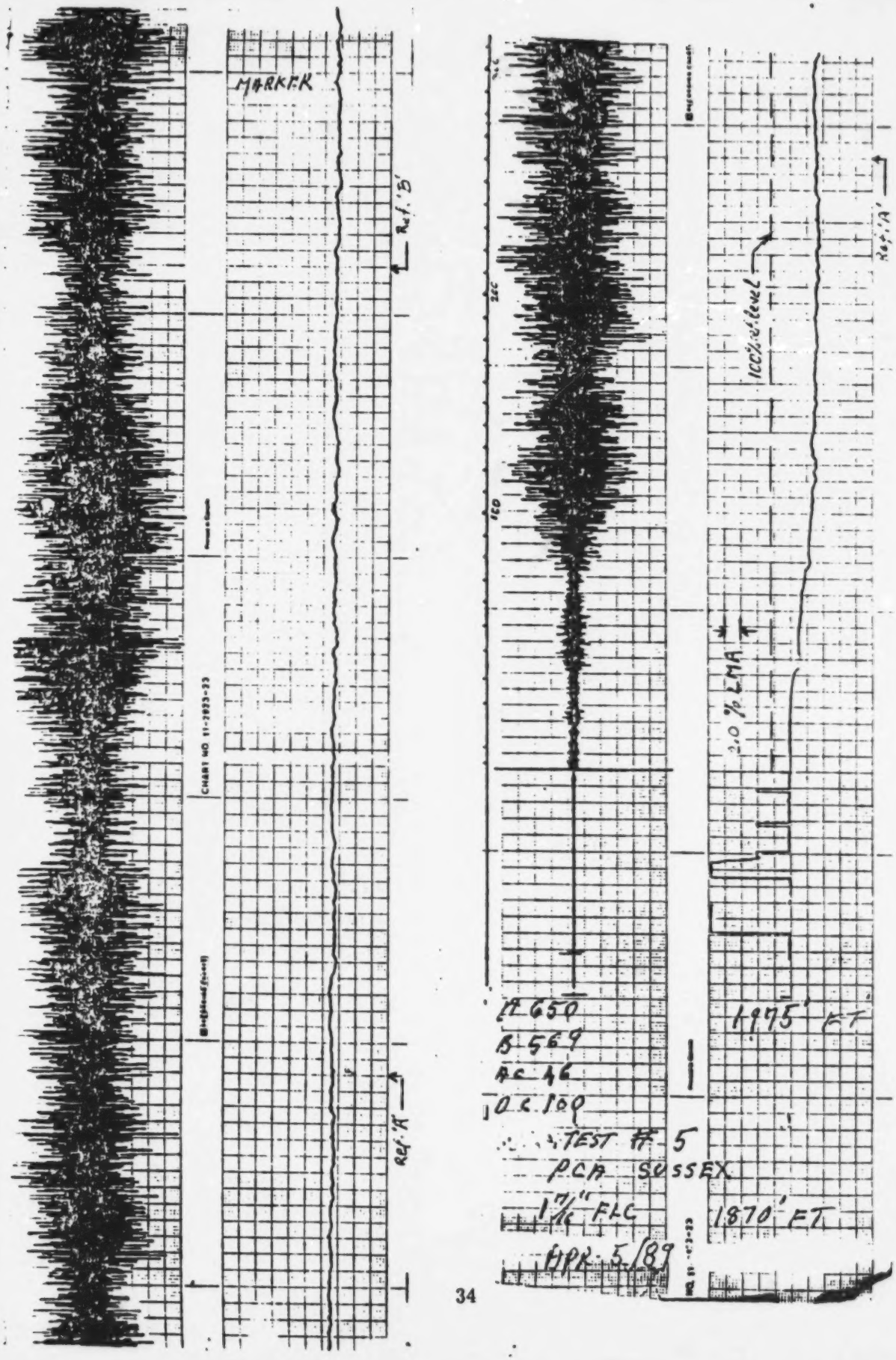

Fig. 9a — Rotescograph shop-floor test of 5.4.89

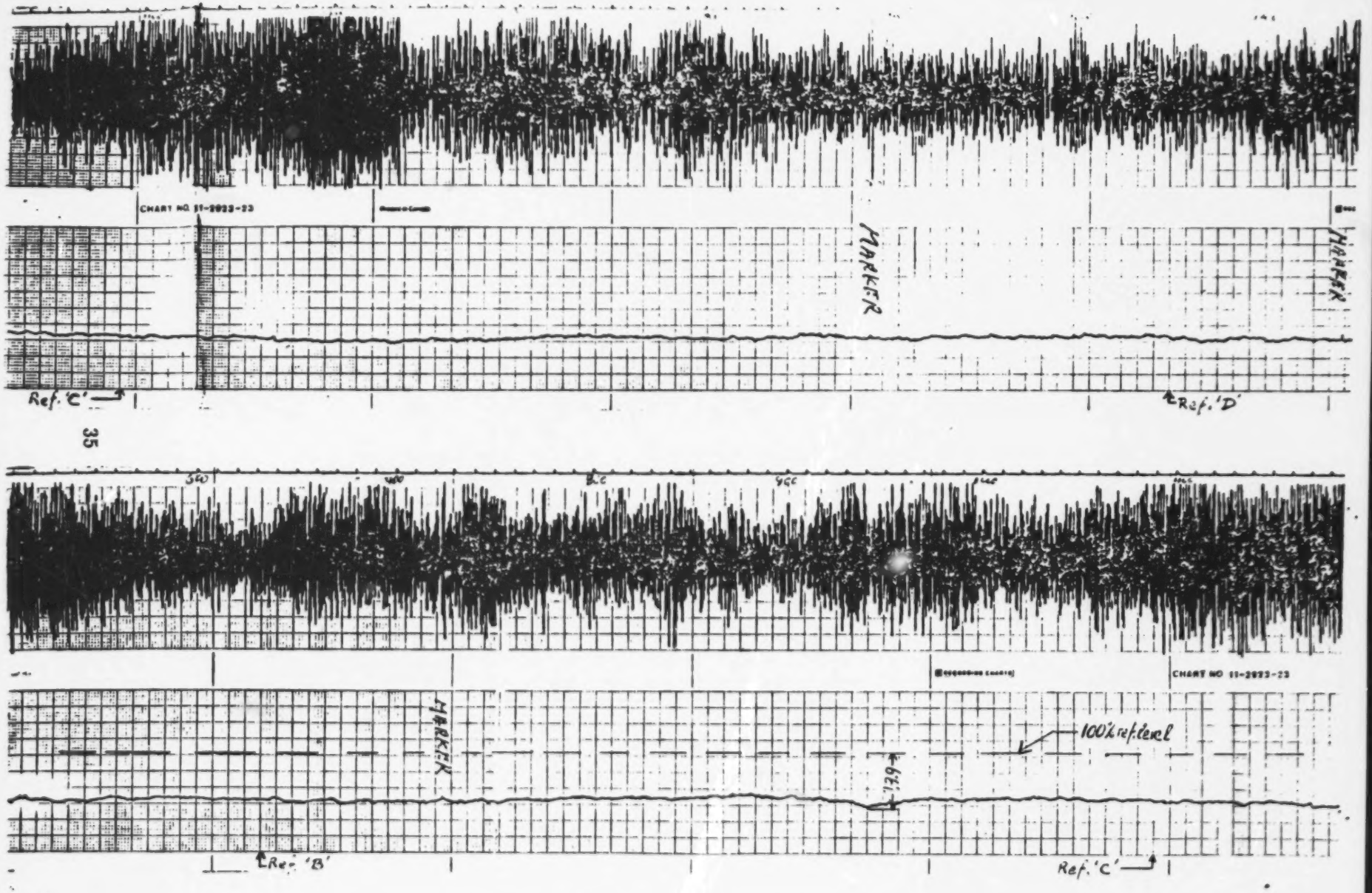

Fig. 9a (continued) — Rotescograph shop-floor test of 5.4.89

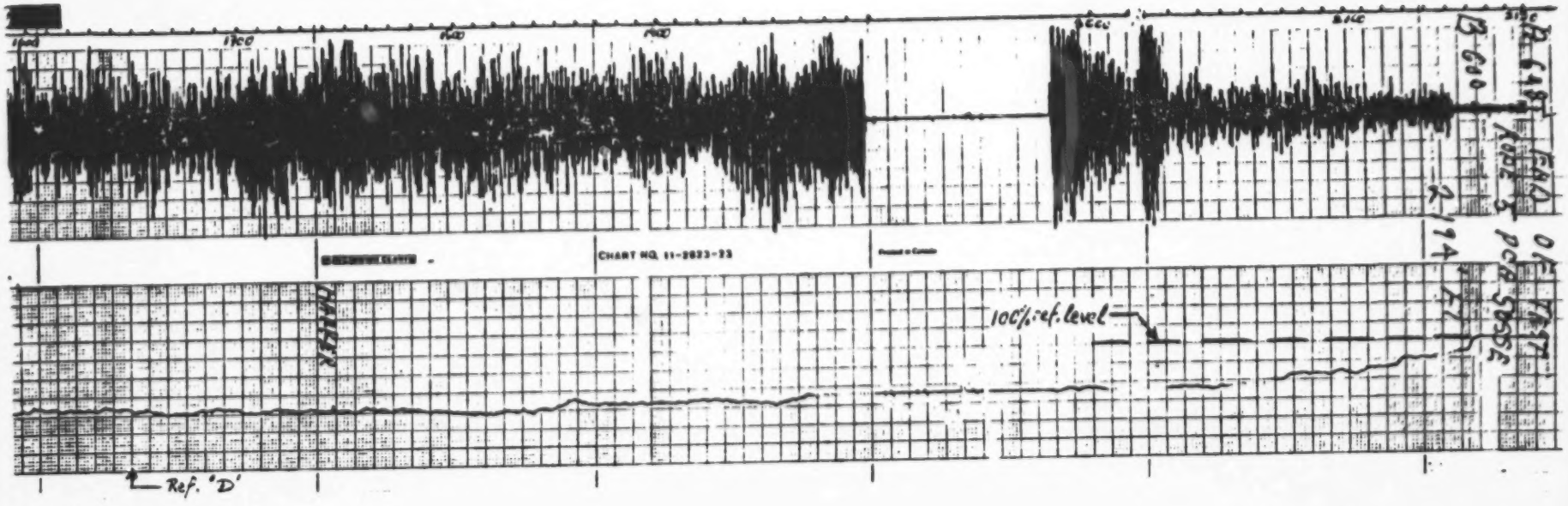

Fig. 0a (continued) — Rotescograph shop-floor test of 5.4.89

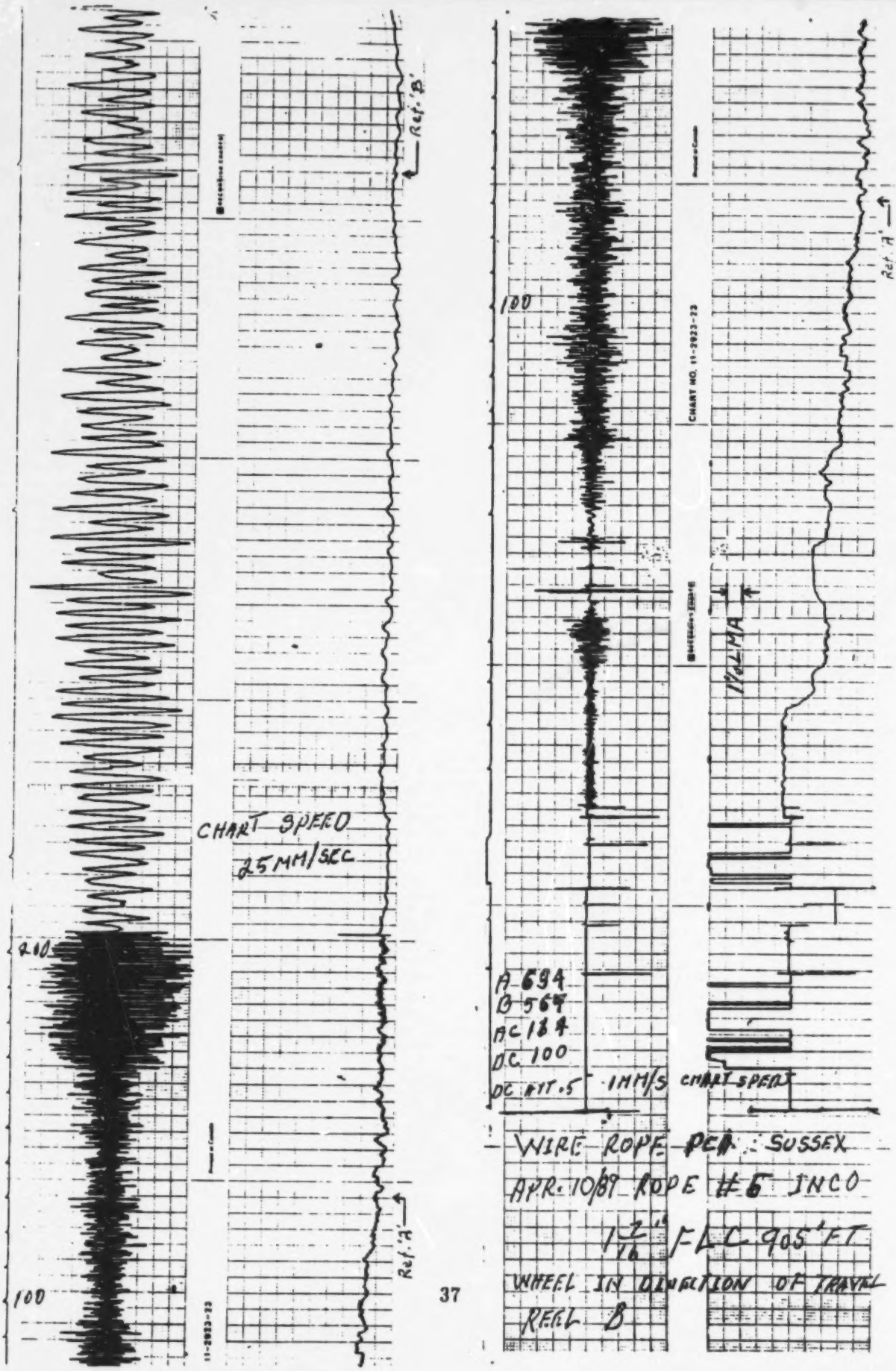

Fig. 9b — Rotescograph shop-floor test of 10.4.89

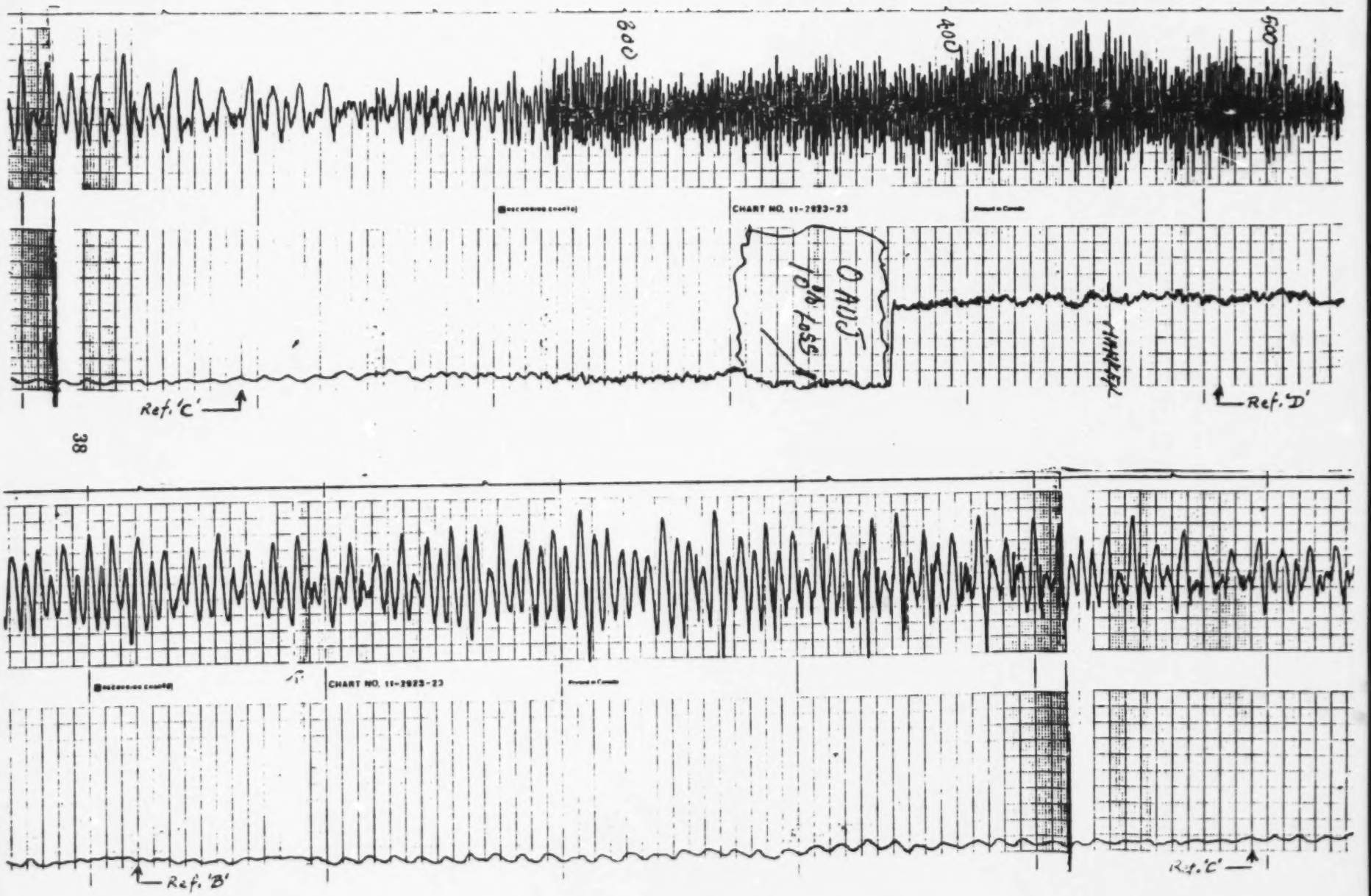

Fig. 9b (continued) — Rotescograph shop-floor test of 10.4.80

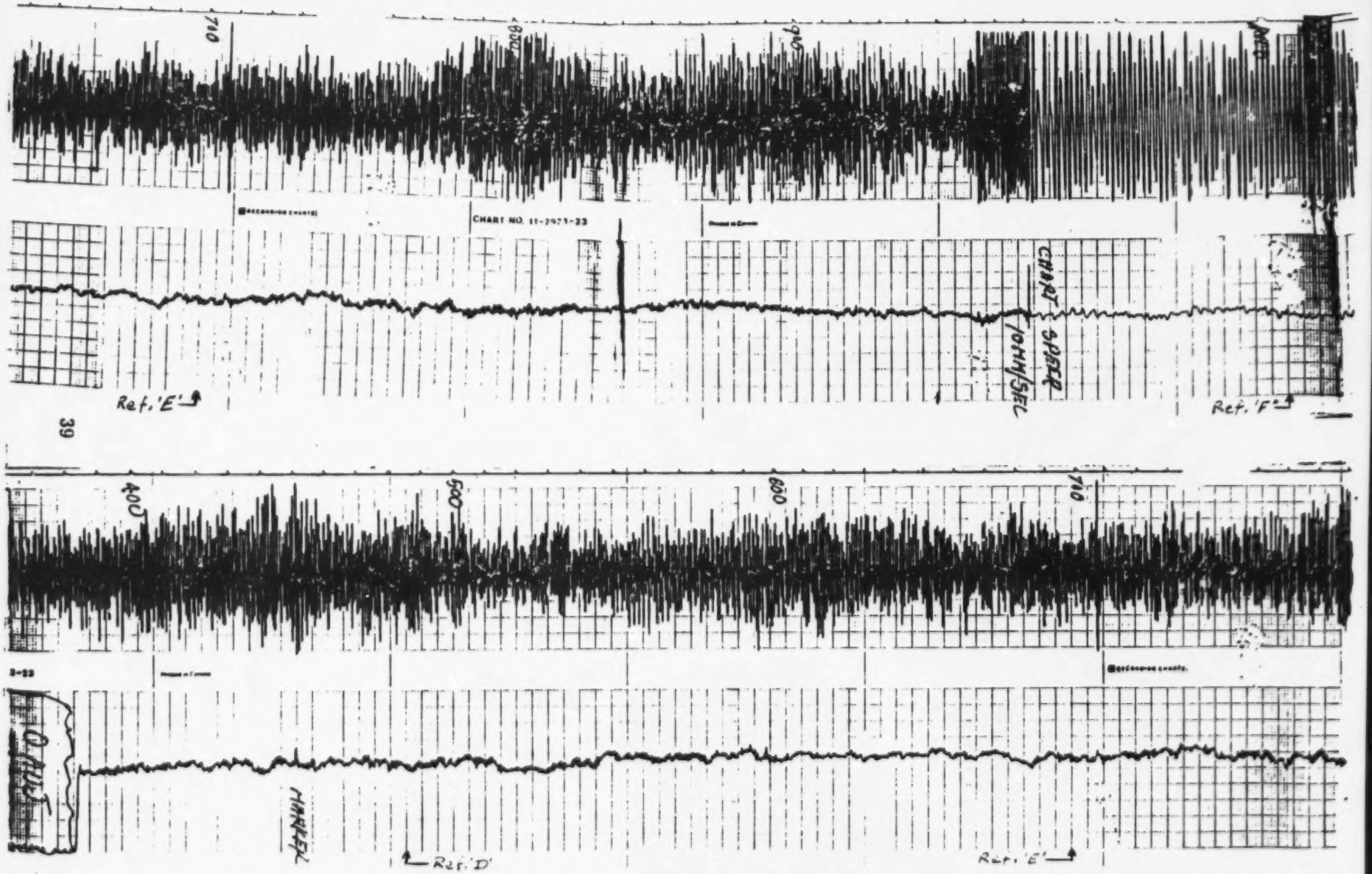

Fig. 0b (continued) — Rotescograph shop-floor test of 10.4.80

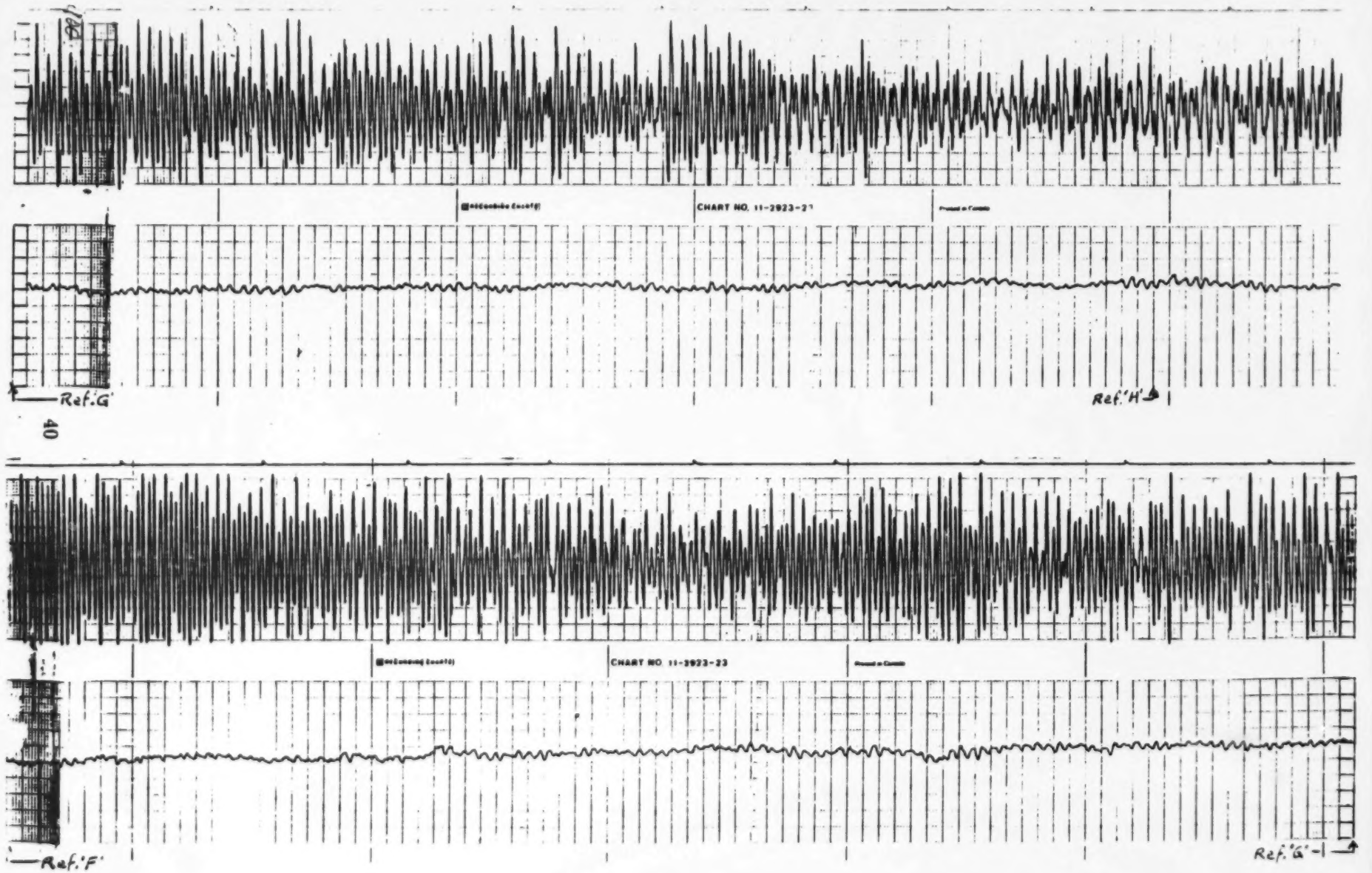

Fig. 9b (continued) — Rotescograph shop-floor test of 10.4.89

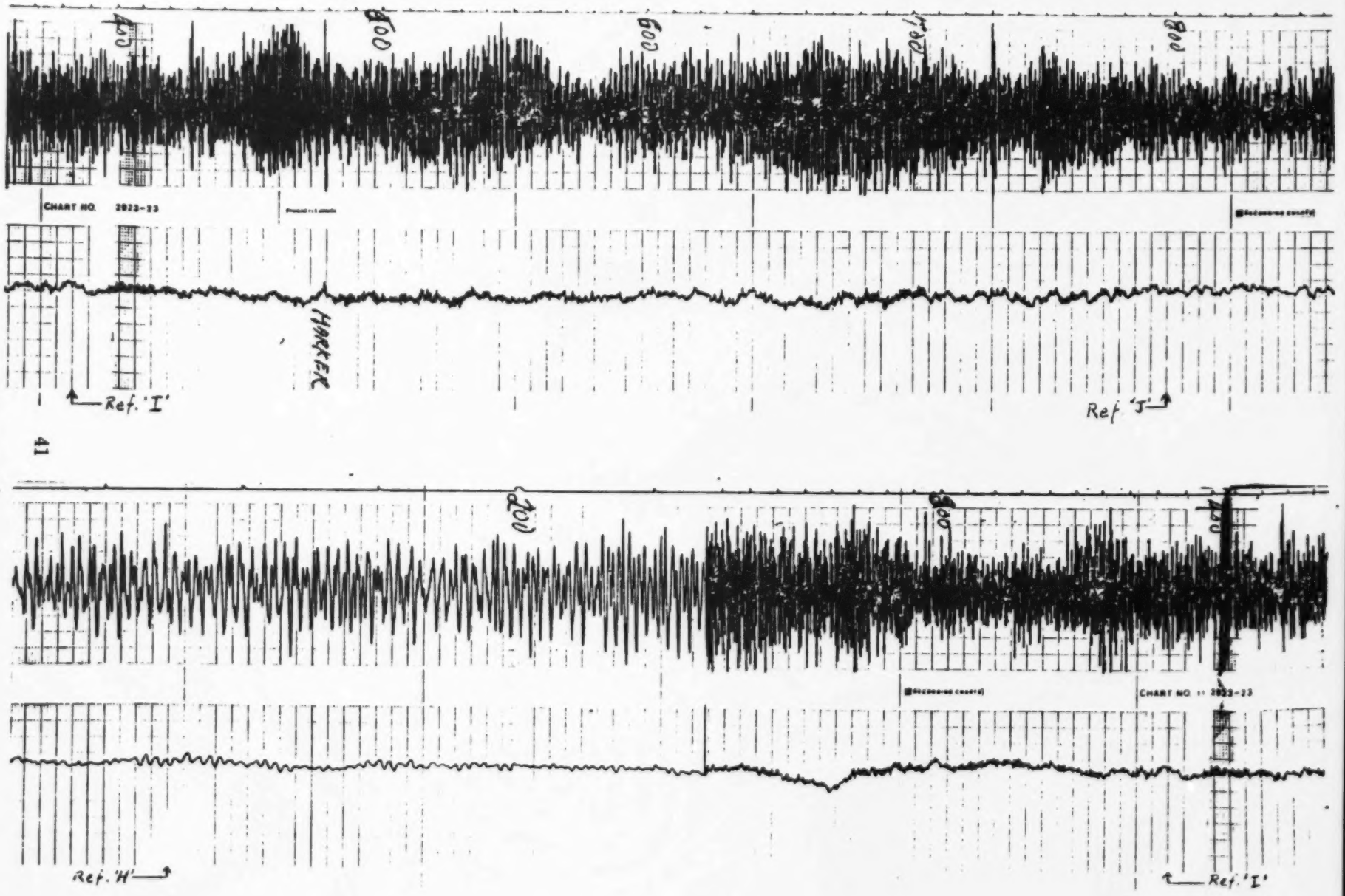

Fig. 9b (continued) — Rotescograph shop-floor test of 10.4.89

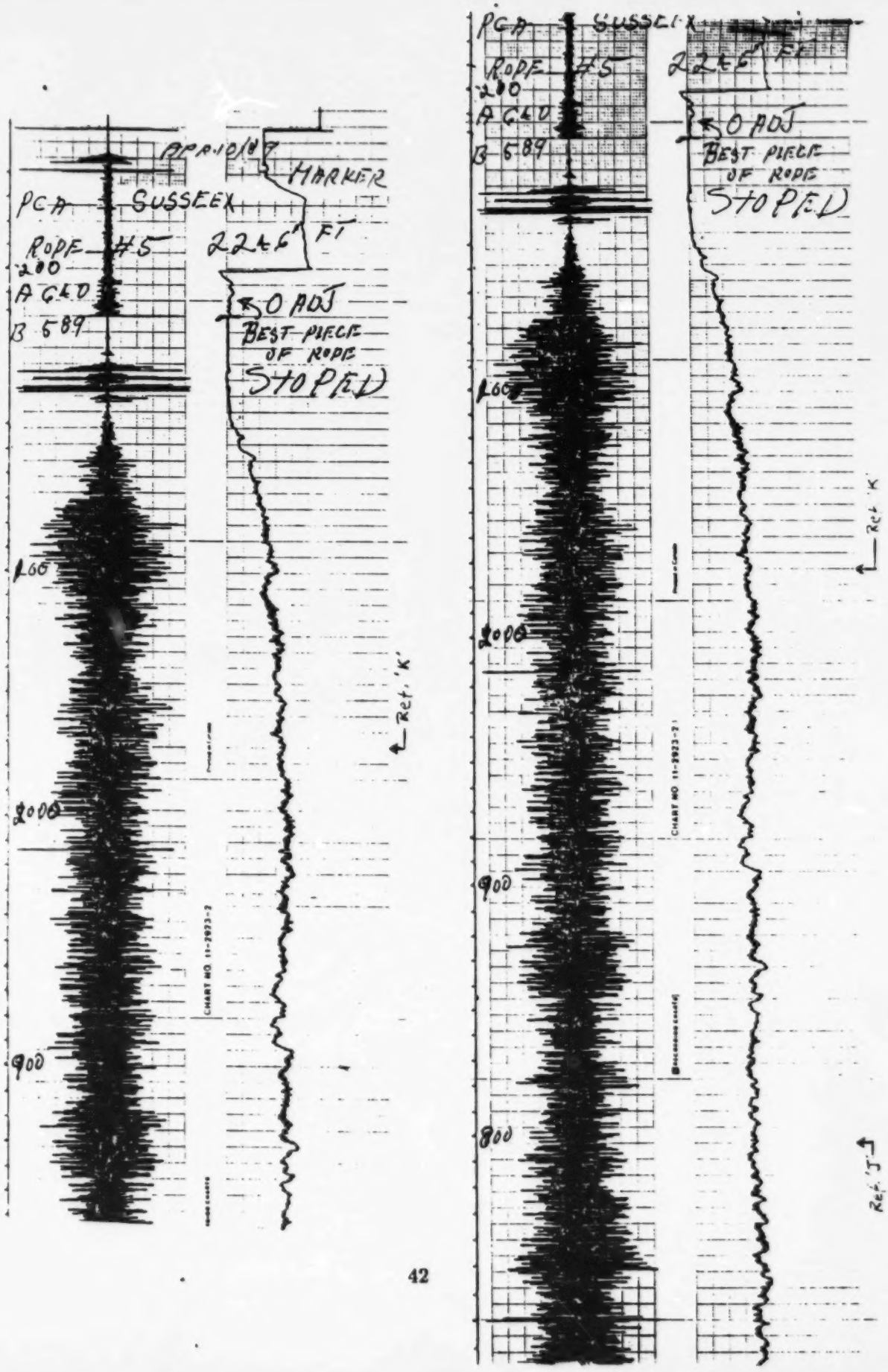

Fig. 9b (continued) — Rotescograph shop-floor test of 10.4.80

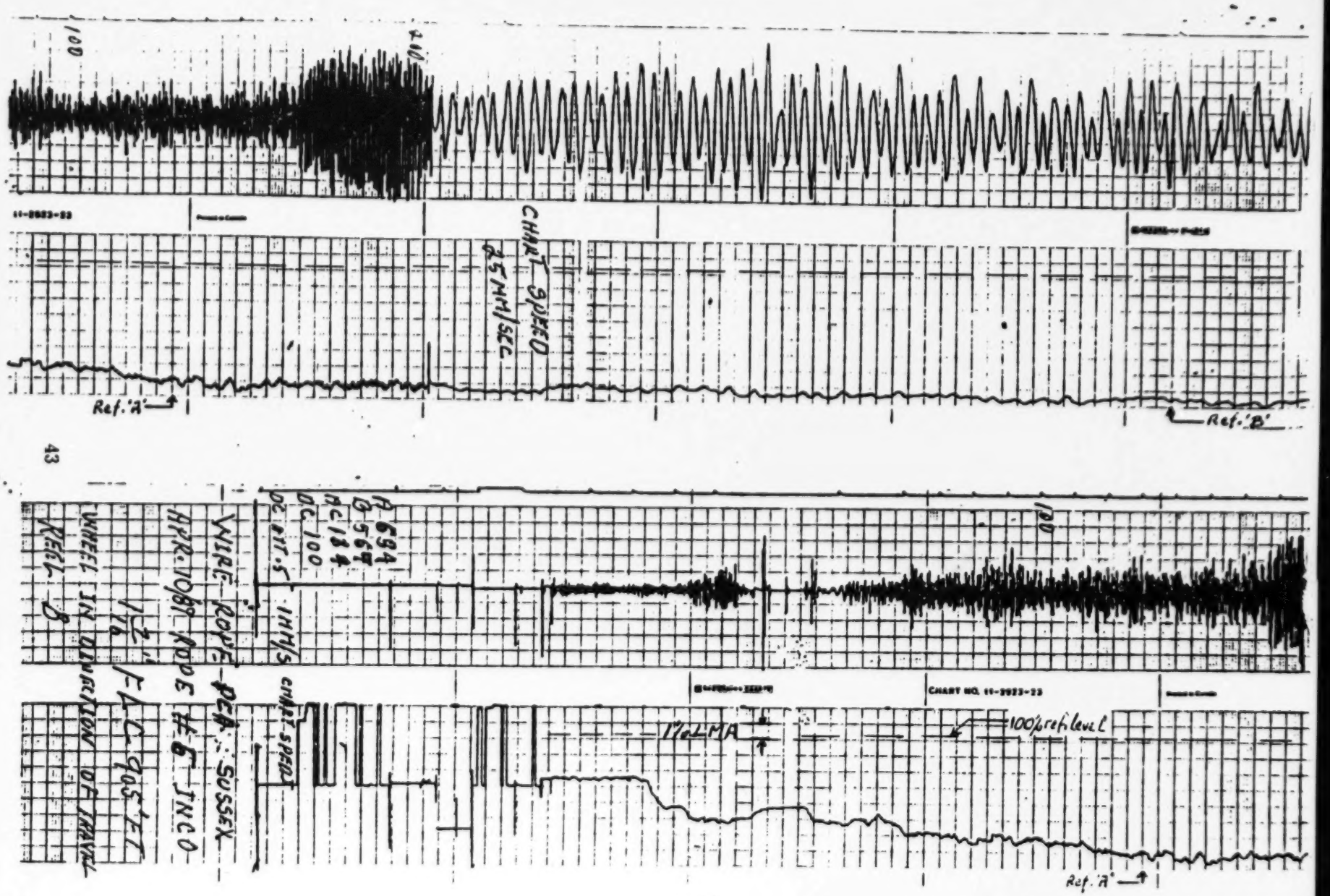

Fig. 9c — Rotescograph shop-floor test of 10.4.89; as marked up by authors

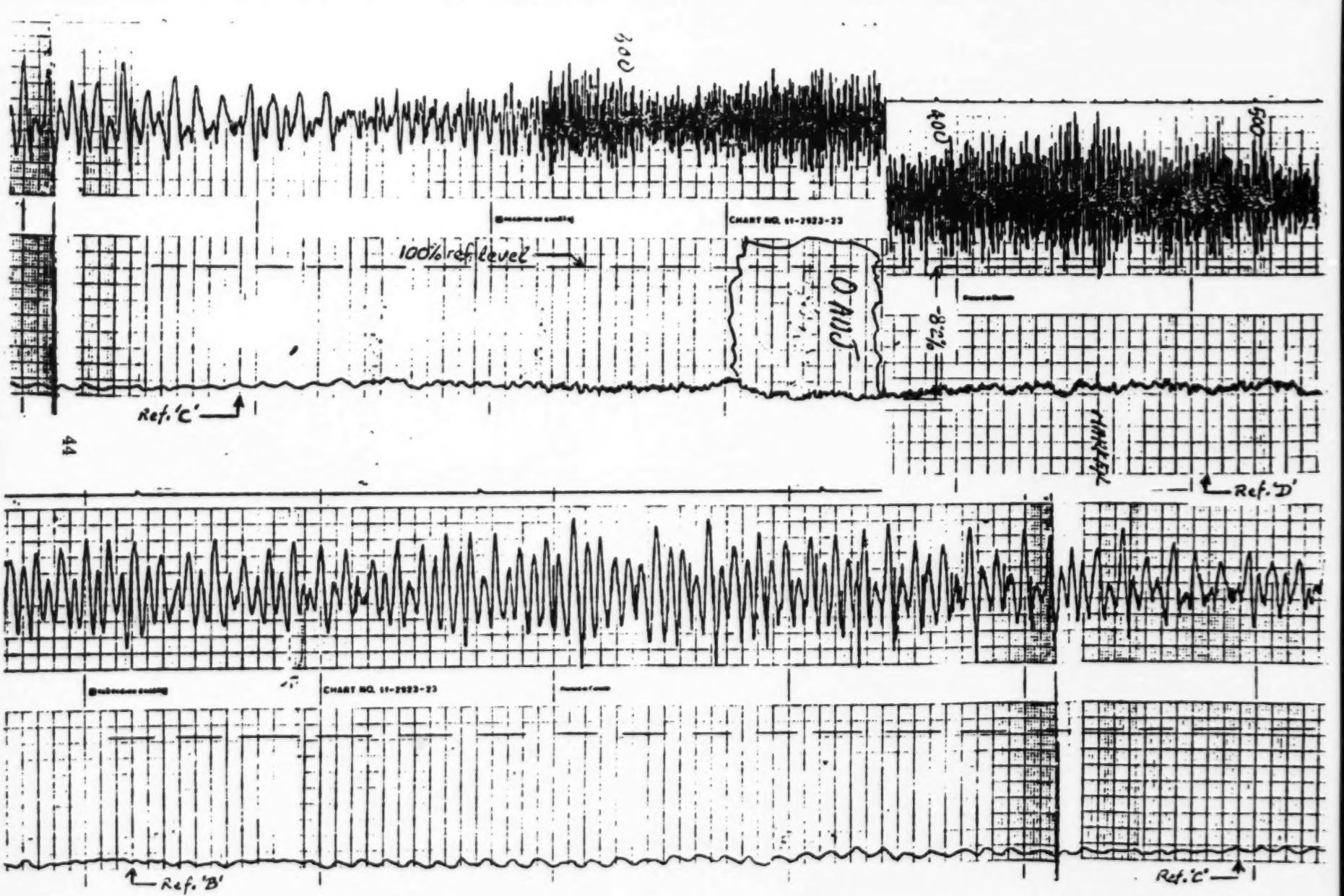

Fig. 9c (continued) — Rotescograph shop-floor test of 10.4.89; as marked up by authors

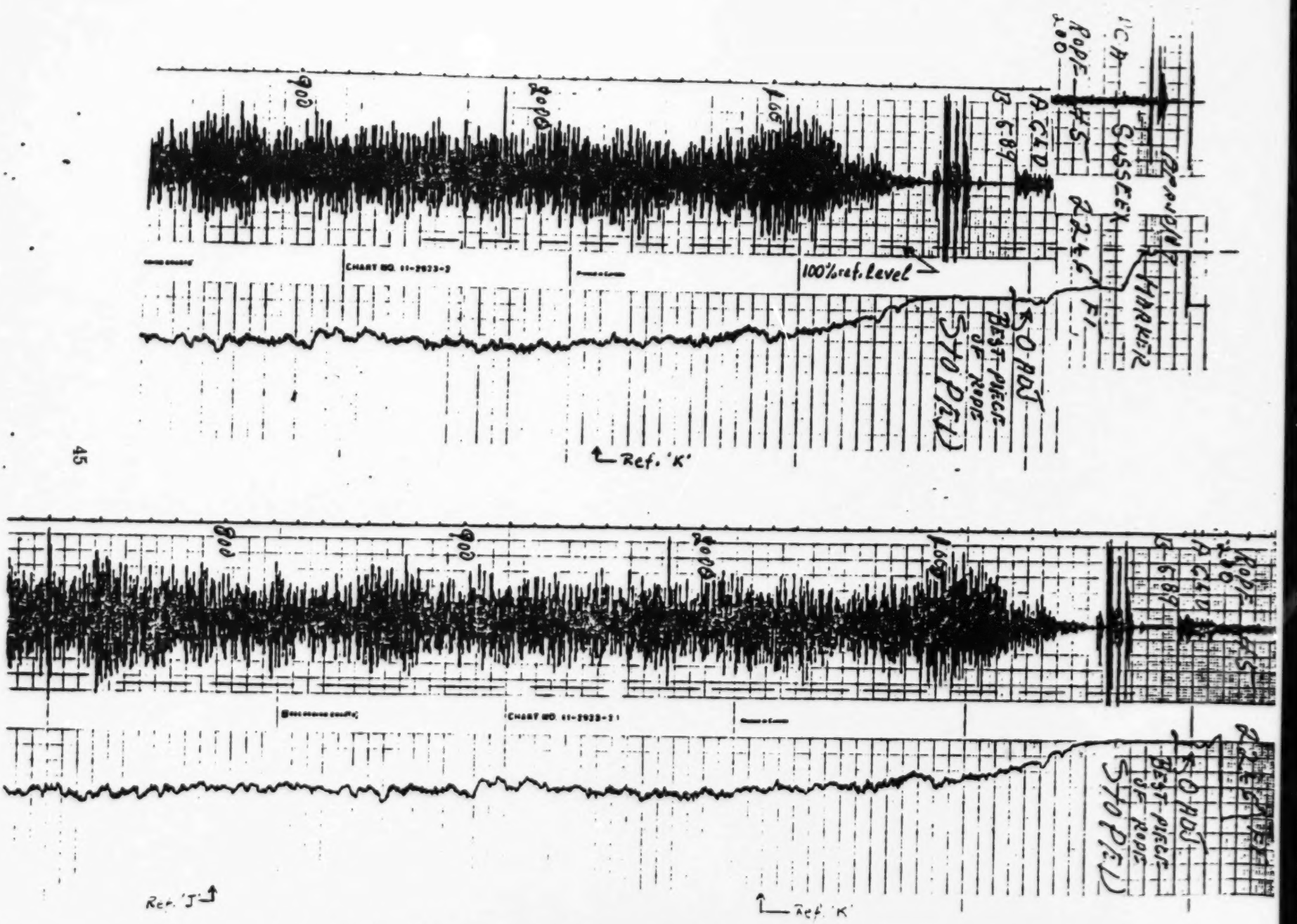

Fig. 9c (continued) — Rotescograph shop-floor test of 10.4.89; as marked up by authors

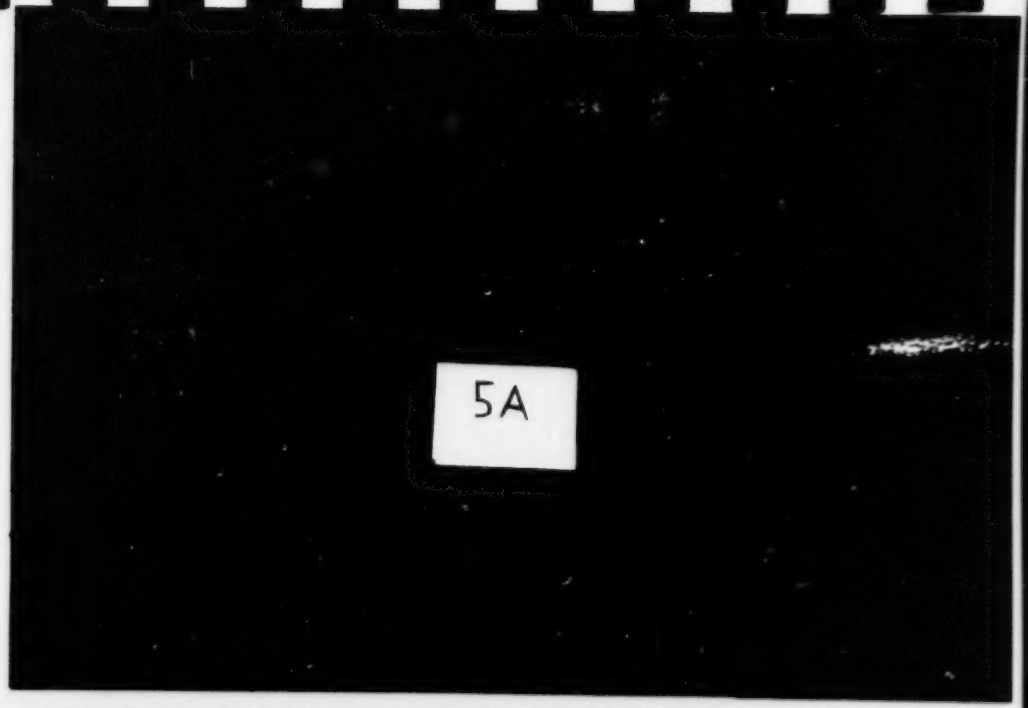

Fig. 10a — Broken sample #5a

Fig. 10 — Broken samples

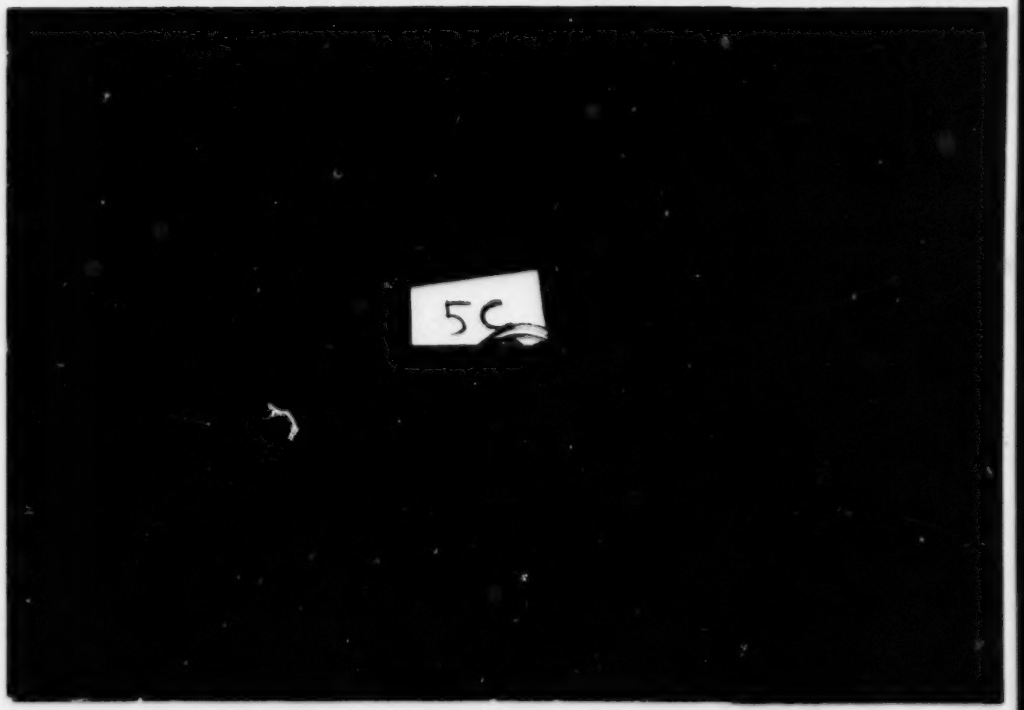

Fig. 10b — Broken sample #5c